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Water Quality Studies: Hartwell Lake 1991 Summary Report

by *William E. Jabour, Joe H. Carroll*
Environmental Laboratory

Prepared for U.S. Army Engineer District, Savannah

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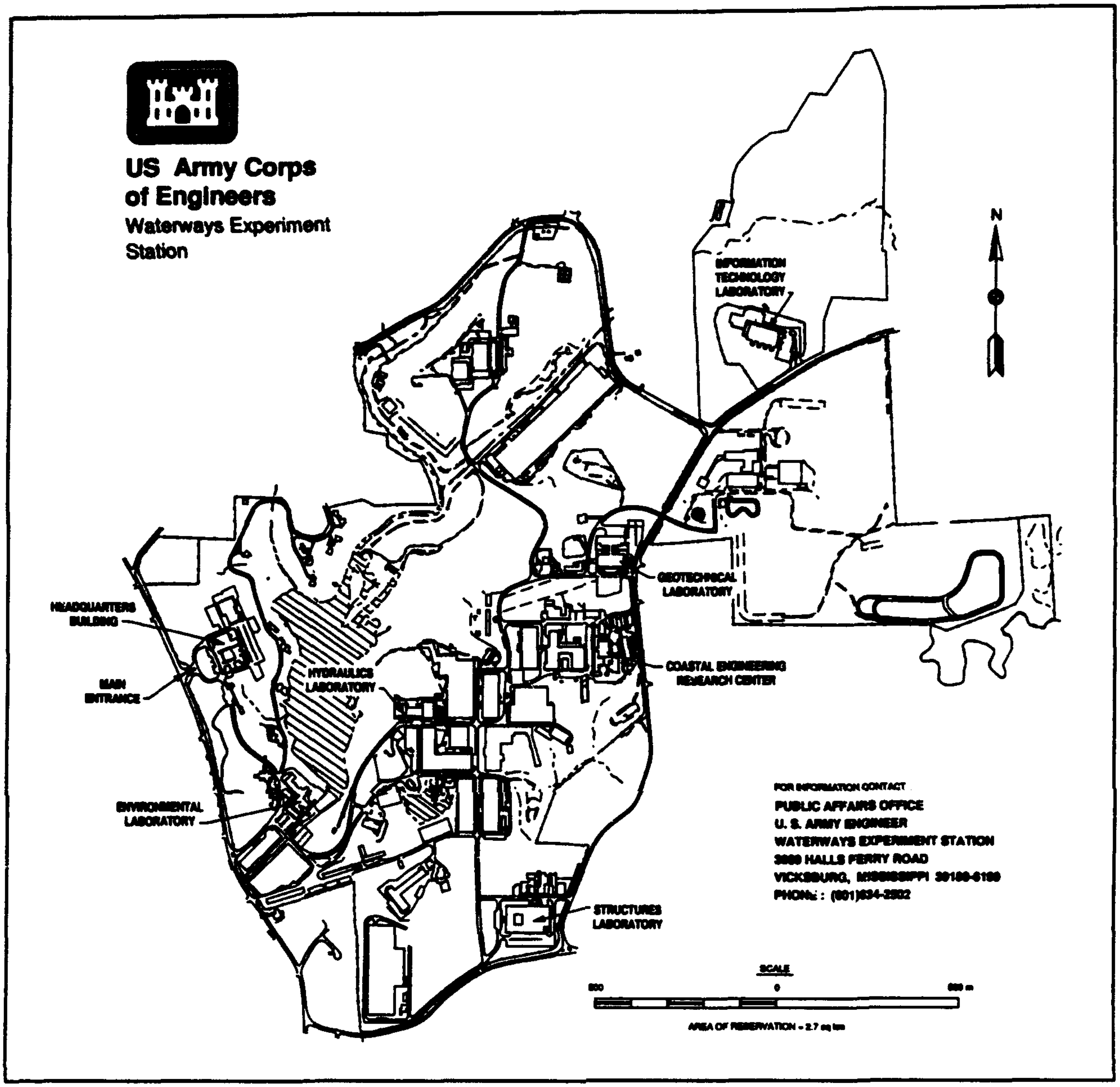

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Contents

Preface

A comprehensive water quality study at Hartwell Lake was initiated in 1991 as a cooperative effort by the U.S. Army Engineer District, Savannah (SAS), and the U.S. Army Engineer Waterways Experiment Station (WES). This report, which covers the period January through December 1991, is the first annual report documenting findings and results.

The principal investigators for this work were Dr. Robert H. Kennedy and Mr. Joe H. Carroll, Ecosystem Processes and Effects Branch (EPEB), Environmental Laboratory (EL), WES. The report was prepared by Messrs. William E. Jabour and Joe H. Carroll, EPEB. Field and technical support were provided by the following Trotters Shoals Limnological Research Facility (TSLRF) personnel: Dr. John J. Hains, EPEB, and Dr. Edward Robertson, Messrs. Michael C. Vorwerk and Mike Madden, and Mses. Cynthia J. Huffstetler and Kim O. Johnson, AScI Corporation, McClean, VA.

Additional assistance was provided by Messrs. Steve Mason and Kenneth Bedenbaugh, SAS, under the supervision of Mr. Dick Austin, SAS. Technical reviews of this report were provided by Drs. Kennedy and Hains and Mr. Steve Ashby, EPEB.

This investigation was performed under the supervision of Dr. Richard E. Price, Acting Chief, EPEB; Mr. Donald L. Robey, Chief, Environmental Processes and Effects Division; and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Introduction

Hartwell Lake (HW), a 22,400 ha impoundment of the Savannah River, was completed in 1962. The project provides hydroelectric power production, flood control, water supply and recreational usage. Hartwell Lake is one of the top three most visited Corps of Engineers lakes in the nation, attracting 14 million visitors annually. In 1991, water quality concerns were addressed in the planning and execution of a comprehensive study of Hartwell Lake. The major objectives of this investigation were to:

(1) Describe longitudinal water quality trends from the forebay region into the upper Seneca and Tugaloo River tributary embayments during both the stratified and mixed periods.

(2) Compare and contrast temporal water quality trends at near-dam stations and those in upstream embayments during a one year period encompassing both stratified and mixed periods.

(3) Assess the onset, formation and extent of hypolimnetic anoxia through the lake.

(4) Monitor release water quality in the Richard B. Russell Lake headwaters through continuous remote sampling in the Hartwell Dam tailrace.

(5) Provide recommendations regarding Hartwell Dam operational procedures for the purpose of improving in-lake and release water quality conditions.

This report documents the results of comprehensive water quality studies performed in Hartwell Lake during the period January through December 1991. Presented in this report are summaries of water quality conditions observed during monthly in situ sampling trips and biannual chemical sampling trips within the main stem and the two major tributary embayments on Hartwell Lake.

Study Site Description

Hartwell Lake was completed by the U.S. Army Corps of Engineers in 1962 as part of a comprehensive water resource development plan for the Savannah River basin. Located between Georgia and South Carolina, Hartwell Lake is a multi-purpose project and one of the most popular Corps impoundments in the nation. The lake has a surface area of nearly 22,400 ha, a shoreline of 1530 km, and a drainage area greater than 5400 km^2. Hartwell Lake extends approximately 79 km from Hartwell Dam to Yonah Dam on the Tugaloo River and 66 km to Keowee Dam on the Seneca River. The former confluence of the two rivers, which formed the Savannah River at that point, is located 11 km upstream of Hartwell Dam. Hartwell Lake is situated immediately upstream of Richard B. Russell Lake on the Savannah River. At normal full pool elevation (201 m NGVD),mean depth and maximum depths are 14 and 55 m, respectively. Hartwell Dam, an earthen and concrete structure, spans approximately 5440 *m across the Savannah River*. The concrete section is 570 m in length and rises to a height of 61 m above the riverbed. The powerhouse contains one 80-MW and four 66-MW generators, providing a total rated capacity of 344 megawatts. Average annual output is 453,000 megawatt-hours of electricity. Average outflow from Hartwell Dam in 1991 was 4180 cfs. Generation is conducted on a schedule dependent on area power requirements and consumption, typically during periods of peak power demand.

Methods and Materials

Routine in situ sampling was conducted monthly throughout the year with the exception of January, April and December. Temperature, dissolved oxygen, pH and conductivity were measured to describe temporal and spatial patterns of water quality within the main stem and the two major tributary embayments on Hartwell Lake. Spatial and temporal chemical trends were documented during July and October and coincided with mid-summer stratification and fall mixing periods. Water samples were collected at selected stations in Hartwell Lake and analyzed at the U.S. Army Engineer Waterways Experiment Station (WES), Trotters Shoals Limnological Research Facility. Chemical analyses for nutrients, organic carbon, turbidity and alkalinity were conducted.

Fourteen sampling stations were selected in Hartwell Lake and tailrace (Figure 1). A total of fifteen water quality variables were monitored during the 1991 study (Table 1).

Routine monitoring of temperature, dissolved oxygen, pH and conductivity was conducted *in-situ* using a Hydrolab Surveyor II (Hydrolab Corporation, Austin, TX). Water samples were collected using a pump and hose at depths selected to reflect effects of thermal stratification. Sample depths included the surface, bottom of the thermocline, and bottom waters at each lake station. Samples were refrigerated prior to analyses. Standard methods (U.S. Environmental Protection Agency 1979, American Public Health Association 1985) were used for laboratory analyses of water samples.

Hourly Hartwell Lake tailwater *in-situ* data (temperature, dissolved oxygen, pH and conductivity) were collected continuously at station 200 with a Schneider Model RM25 Water Quality Monitor (Schneider Instrument Company, Madeira, Cincinnati, OH). This unit was calibrated weekly during the stratified period using known standards.

Results and Discussion

Precipitation, pool elevation, mean daily inflow and mean daily outflow for the period 1990-1991 are depicted in Figure 2. The chemical sampling trips during July and October coincided with the highest and lowest precipitation amounts, respectively, recorded for the calendar year. Consequently, greater than normal rainfall during the spring and summer of 1991 in addition to higher inflow levels resulted in pool elevations considerably greater than those of the preceding year. This in turn led to increased outflow releases during the summer stratified period, significantly altering water quality conditions within the tributary embayments and forebay of Hartwell Lake.

Spatial and seasonal thermal patterns for Hartwell Lake are presented in Figures 3 and 4. The onset of thermal stratification was observed during late March, and an extensive, well-established thermocline was present by mid-May. Stratification was present from Hartwell Dam to the headwaters of the Tugaloo and Seneca River tributary embayments from May through September. Both embayments exhibit similar spatial patterns in regard to temperature during July and October. Monthly temperature variability at station 210 in the Hartwell Dam forebay exemplify the seasonal pattern of thermal development in the lake (Figure 5). The gradual deepening of the thermocline at the near-dam station can be attributed to penstock withdrawals from the cooler hypolimnion. During the majority of the summer stratified period the thermocline remained at a depth of 10 to 15 m in the upstream embayments. Temperatures in the epilimnion were between 24 and 29°C, and hypolimnetic temperatures ranged from 14 to 20°C during stratification. Cooling in late September and October decreased surface water temperatures, lessening vertical thermal gradients. Continued cooling and fall mixing resulted in near-isothermal conditions by November.

Marked gradients in dissolved oxygen were observed from the dam to the headwaters of both tributary arms (Figures 6 and 7). Hypolimnetic oxygen depletion was initially observed in the mid-reaches of both tributaries in June. Anoxic conditions formed more rapidly and were more extensive in the Seneca River than in the Tugaloo River embayment. This is believed to be the result of greater introduction of organic material through inflow loading into the Seneca River embayment. Hypolimnetic releases through Hartwell Dam during the summer months contributed to a reduction and downstream progression of the anoxic zones within both upstream

embayments. By October, upstream reaeration had occurred, although anoxic conditions persisted from the deep-water stations of the Seneca River to Hartwell Dam.

Dissolved oxygen conditions in the Hartwell Lake forebay are depicted in Figure 8. Anoxia in the forebay bottom waters was first observed in mid-August and, although diminished, persisted until early November.

Results of in situ pH measurements are exhibited in Figures 9 and 10. Minimum and maximum values in July ranged from 7.8 to 6.2, compared to 7.0 to 6.2 in October. Maximum levels occurred in near-dam surface waters during July, reflective of high productivity within the photic zone. Maximum concentrations during October were associated with Seneca embayment inflows, while the Tugaloo embayment showed little variability.

Increases in specific conductance values coincident with anoxic conditions were observed in the mid-reaches of the Seneca and Tugaloo Rivers during July and in the deep-water stations in October (Figures 11 and 12). While conductivity measurements ranged 30-40 µS lakewide throughout much of the year, values in anoxic bottom waters during July increased to approximately 70 µS in the Seneca River embayment and 50 µS in the Tugaloo River embayment. A maximum specific conductance value of 80 µS was reported in October in the deep-water stations near Hartwell Dam. Temporal and vertical changes in specific conductance data were observed at station 210, where conductivity measurements ranged from 32 µS in March to 60 µS during November (Figure 13).

Summaries of Hartwell Lake epilimnetic and hypolimnetic in situ and water chemistry data were compiled for July and October 1991 (Tables 2 through 5). Seasonal trends in the concentrations of chemical variables, as well as longitudinal and vertical gradients, were most pronounced during stratification. Maximum chemical concentrations, coincident with anoxic conditions, were observed in bottom waters of the mid-Seneca River tributary embayment during the July sampling and in the deep-water near-dam stations during the October sampling.

Seneca and Tugaloo River embayment total phosphorus concentrations in July ranged from 0.006 to 0.025 mg/l and from 0.006 to 0.012 mg/l, respectively, with the greatest concentrations in the mid to upper reaches (Figures 14 and 15). These concentrations reflect probable external loading from lakeside development and/or small tributaries. By October, concentrations showed an overall increase, from 0.020 to 0.110 mg/l in the Seneca River and from 0.015 to 0.045 mg/l in the Tugaloo River embayments. Elevated levels in the Seneca River embayment during October indicate a source of considerable loading in the vicinity of a single sampling station. During July, total soluble phosphorus (TSP) and soluble reactive phosphorus (SRP) concentrations were measured at or just above detection limits (Figures 16 through 19). Maximum concentrations of both TSP and SRP were observed during October in bottom waters near HW Dam.

Total nitrogen concentrations reflected the occurrence of anoxic conditions in Hartwell Lake (Figures 20 and 21). In July, Seneca River embayment concentrations ranged from 0.3 to 0.7 mg/l vertically at the upstream stations. Upper Tugaloo River embayment concentrations ranged from 0.3 to 0.5 mg/l. October maximum concentrations of approximately 0.8 mg/l were recorded at the downlake deepwater stations. Dissolved nitrogen concentrations followed temporal and longitudinal patterns similar to total nitrogen in both tributary embayments (Figures 22 and 23).

Maximum ammonia-nitrogen concentrations were observed coincident to anoxia in the mid-reaches of both embayments in July and in the bottom waters of near-dam stations in October (Figures 24 and 25). Ammonia concentrations within the anoxic hypolimnion are attributable to organic decomposition and release from bottom sediments. Ammonia-nitrogen concentrations lakewide ranged from 0.1 to 0.7 mg/l. Nitrate is an oxidized form of nitrogen that commonly occurs under aerobic conditions. Nitrate is derived from ammonia conversion in the presence of dissolved oxygen, although rapid utilization by biota prevents accumulation equal to that of ammonia under anaerobic conditions. Consequently, maximum nitrate-nitrogen concentrations in July were recorded in the downlake deep water stations and ranged from 0.05 to 0.25 mg/l, while detection limit concentrations were observed in October (Figures 26 and 27). Increased concentrations of nitrate-nitrogen occurred during July in the upper Seneca River.

Changes in organic carbon concentrations coincided with anoxic conditions during October in Hartwell Lake (Figures 28 through 31). Total organic carbon concentrations in July ranged from 0.8 to 1.2 mg/l and from 0.4 to 1.2 mg/l in the Seneca and Tugaloo River embayments, respectively. Dissolved organic carbon concentrations followed similar patterns, ranging from 0.6 to 1.2 mg/l and from 0.4 to 1.0 mg/l, respectively. However, no defined vertical or longitudinal patterns in organic carbon concentrations were discernable. During October, Seneca River embayment total organic carbon concentrations ranged from 1.0 to 2.6 mg/l with maximum concentrations occurring in the anoxic downstream region. Tugaloo River embayment concentrations ranged from 1.3 to 2.3 mg/l, with greatest values occurring at downstream sites coincident with anoxic conditions. Dissolved organic carbon concentrations exhibited similar distribution patterns ranging from 1.0 to 2.5 mg/l and from 0.9 to 2.3 mg/l in the Seneca and Tugaloo River embayments.

Although the Hartwell Lake system is weakly buffered, gradients in total alkalinity concentrations were observed in July and October (Figures 32 and 33). Maximum variability in alkalinity coincided with the presence of anoxic conditions, ranging from 8 to 18 mg/l in the tributary embayment mid-reaches in July and in the deepwater near-dam stations in October. In addition, upstream inflows during July and October resulted in variable alkalinity measurements.

Turbidity gradients related to tributary inflows and anoxic conditions were recorded in both the Seneca and Tugaloo River embayments (Figures 34 and 35). The Tugaloo River embayment exhibited greater variability in July with gradients in both upper and middle reaches ranging from 2 to 12 NTU, as compared to 2 to 6 NTU in the Seneca River embayment. In October, both tributary embayments exhibited upstream gradients of 2 to 14 NTU. In addition, a maximum of approximately 20 NTU was observed in the deepest Seneca River station.

Temperature, dissolved oxygen and pH in the tailwater displayed seasonal trends reflective of changing conditions in the forebay of Hartwell Lake. Temperatures increased from approximately 10°C in February to 15°C in June and reached a maximum of 21°C during September. Dissolved oxygen concentrations reached 11 mg/l during mid-February and ranged from 2 to 4 mg/l during the late-summer stratified period. By November, average concentrations had risen to approximately 7 mg/l (Figure 36), coincident with fall mixing in the Hartwell Lake forebay. Seasonal variability in pH was observed in the Hartwell tailwater from November through April when values averaged pH 7.0, reflective of upstream algal productivity (Figure 37). July through September data measurements averaged pH 6.1 (Figure 37). These data reflect hypolimnetic withdrawal during the summer stratified period. Tailwater specific conductance values were comparable with forebay measurements throughout the 1991 period and averaged 24 to 32 μS (Figure 38).

Summary

Hartwell Lake, located between Georgia and South Carolina along the Savannah River basin, was the site of an extensive water quality study during 1991. Temporal and longitudinal trends were identified through monthly in situ monitoring and bi-annual chemical analyses.

The onset of thermal stratification began on Hartwell Lake during late March. By May, extensive stratification was present from headwaters to the forebay. Anoxic conditions were first observed in the middle reaches of the Seneca and Tugaloo River embayments during the July sampling. The greatest concentrations of chemical constituents within the tributary embayments were recorded during the mid- to late summer period. Progression of the anoxic zone from the mid-embayments towards Hartwell Dam was observed during the July through October period. Stratification and accompanying anoxia in the upstream regions were diminished by early October due to seasonal cooling and mixing processes. In the deep-water near-dam areas, anoxic conditions persisted until November.

An intensive physicochemical sampling effort during July revealed the presence of increased concentrations of specific nutrients and organic carbons associated with anoxic conditions in the bottom waters of each tributary embayment. Chemical concentrations within the mid-reaches of the Seneca River embayment were consistently greater than those observed within the Tugaloo River arm. July was significant in that the sampling study coincided with the greatest monthly rainfall of the 1991 year.

A second intensive sampling trip conducted in late October revealed that, due to autumnal mixing, anoxia within the tributary embayments no longer existed. Consequently, chemical constituents found in high concentrations within the Seneca and Tugaloo embayments during July were greatly diminished during October. Anoxic conditions were observed in the bottomwaters of the deep near-dam stations. Maximum concentrations of chemical variables were recorded in these areas during October.

Continuous data for temperature, dissolved oxygen, pH and conductivity were collected using a Schneider RM-25 monitor in the tailrace below Hartwell Dam. These data reflected seasonal variability and were indicative of water quality conditions within the Hartwell Lake forebay.

Hartwell Dam outflows during July and August 1991 were nearly double those for the same months during the previous year. This increased outflow was in response to greater than average rainfall. Inflows during August 1991 were three times greater than during August 1990.

In summation, water quality conditions at Hartwell Lake were influenced by multiple factors, including hydrodynamics, loading, climatological conditions, seasonal variability, algal productivity, anoxic development and duration, bottom water-sediment interactions, and additional internal and external limnological processes. Studies conducted on two downstream Savannah River system lakes, Richard B. Russell and J. Strom Thurmond, recorded similar patterns of temporal and longitudinal gradients with regard to in situ and physicochemical parameters. Longitudinal, vertical and temporal variability were readily observed in temperature, dissolved oxygen, pH and specific conductance in situ data during 1991. Nutrient, organic carbon, and alkalinity concentrations were greatly influenced by the presence of anoxia in Hartwell Lake bottom waters.

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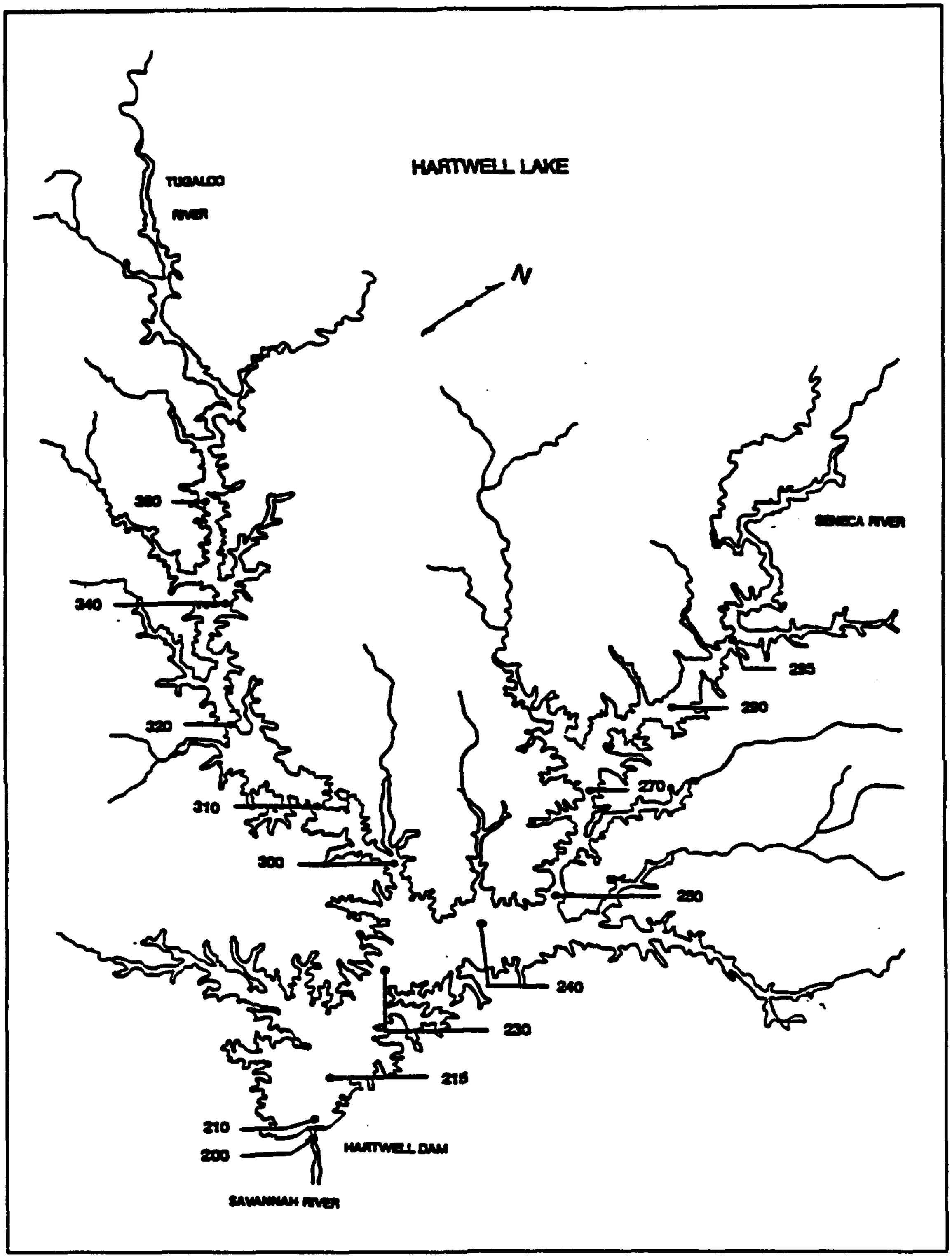


Figure 1.   Sampling stations in Hartwell Lake and tailrace

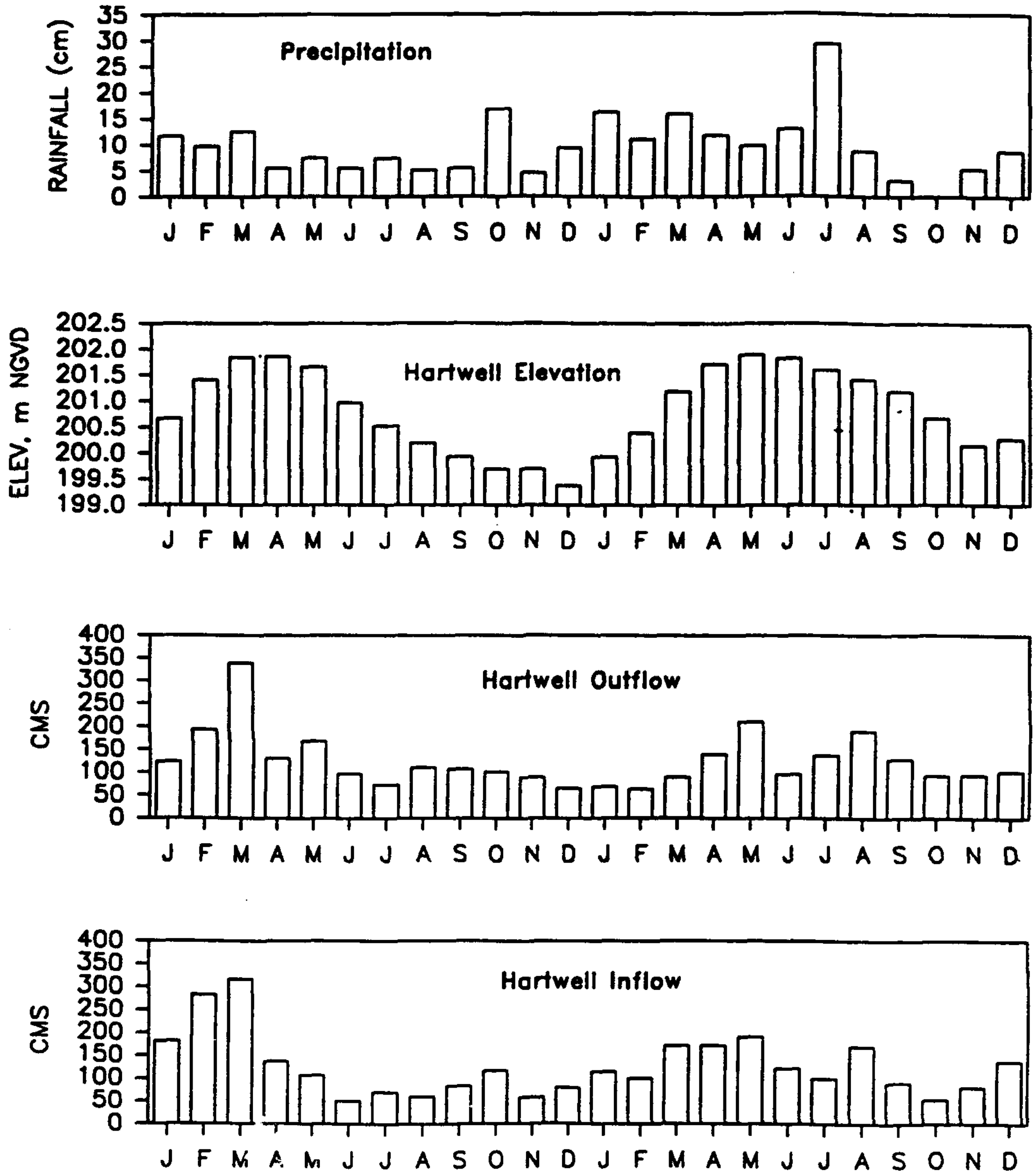


Figure 2. Precipitation, pool elevation, mean daily inflow and mean daily outflow for Hartwell Lake, 1990-1991

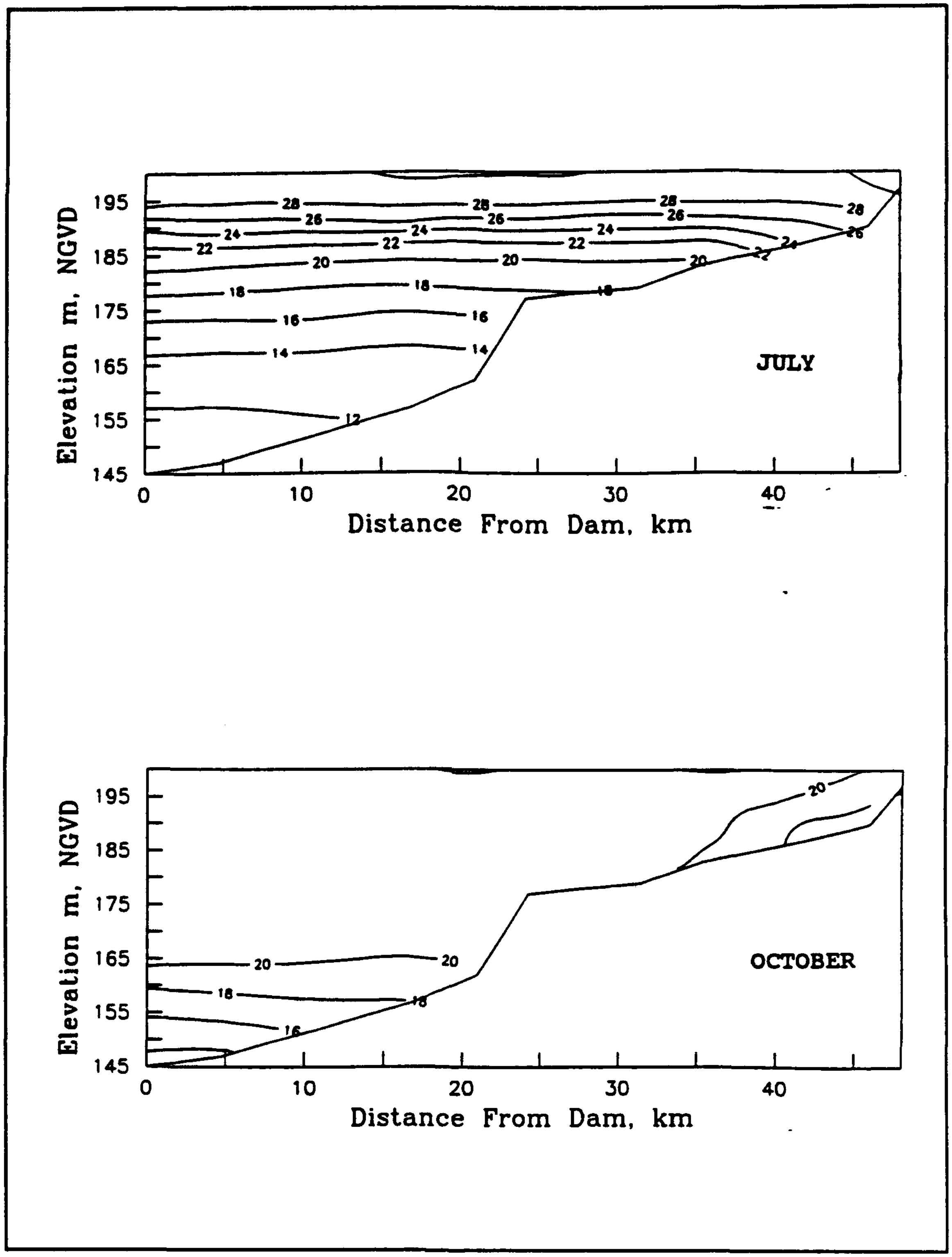


Figure 3. Patterns of spatial distribution of temperatures (°C) from Hartwell Dam to upper Seneca River, July and October 1991

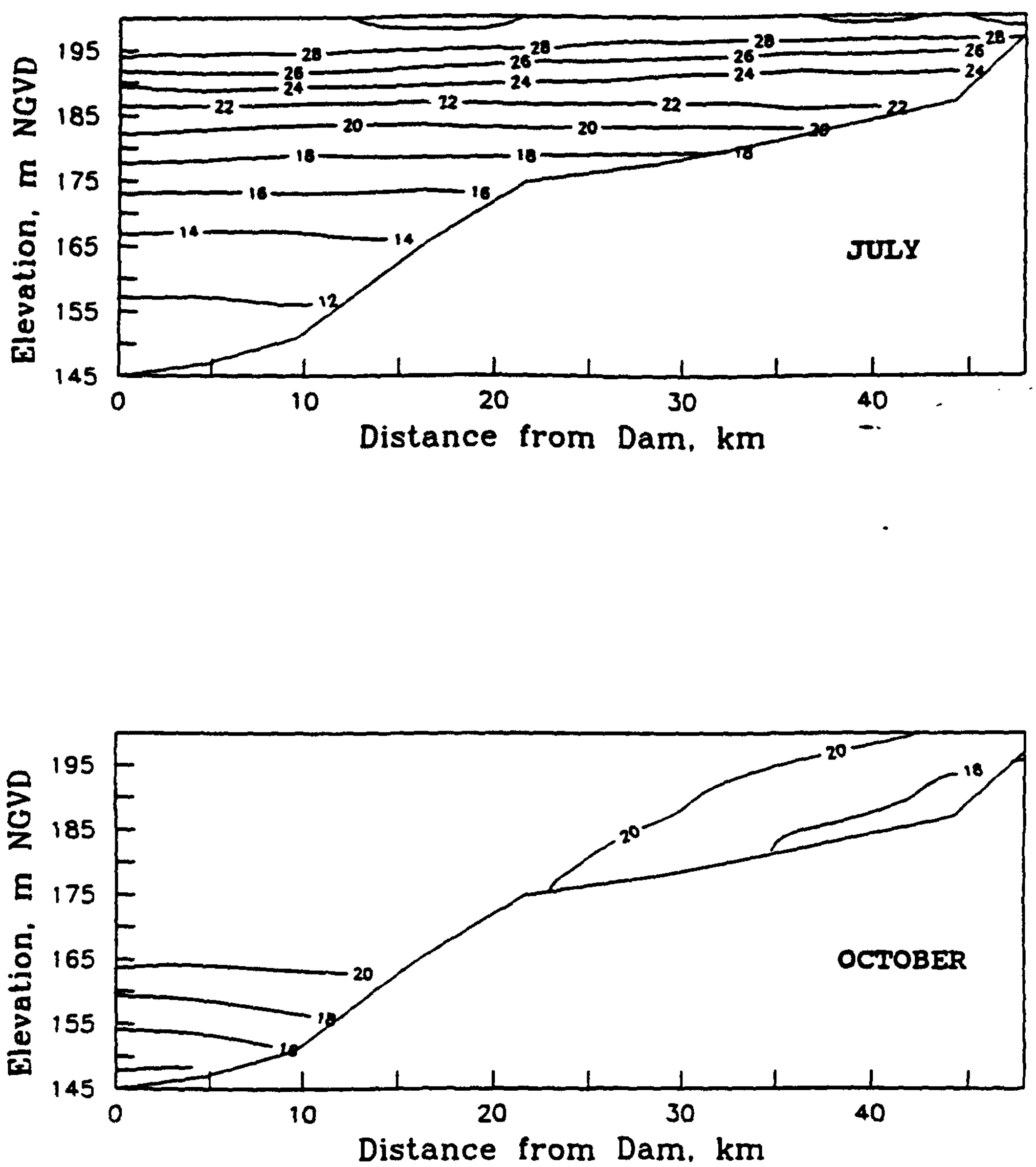


Figure 4. Patterns of spatial distribution of temperatures (°C) from Hartwell Dam to upper Tugaloo River, July and October 1991

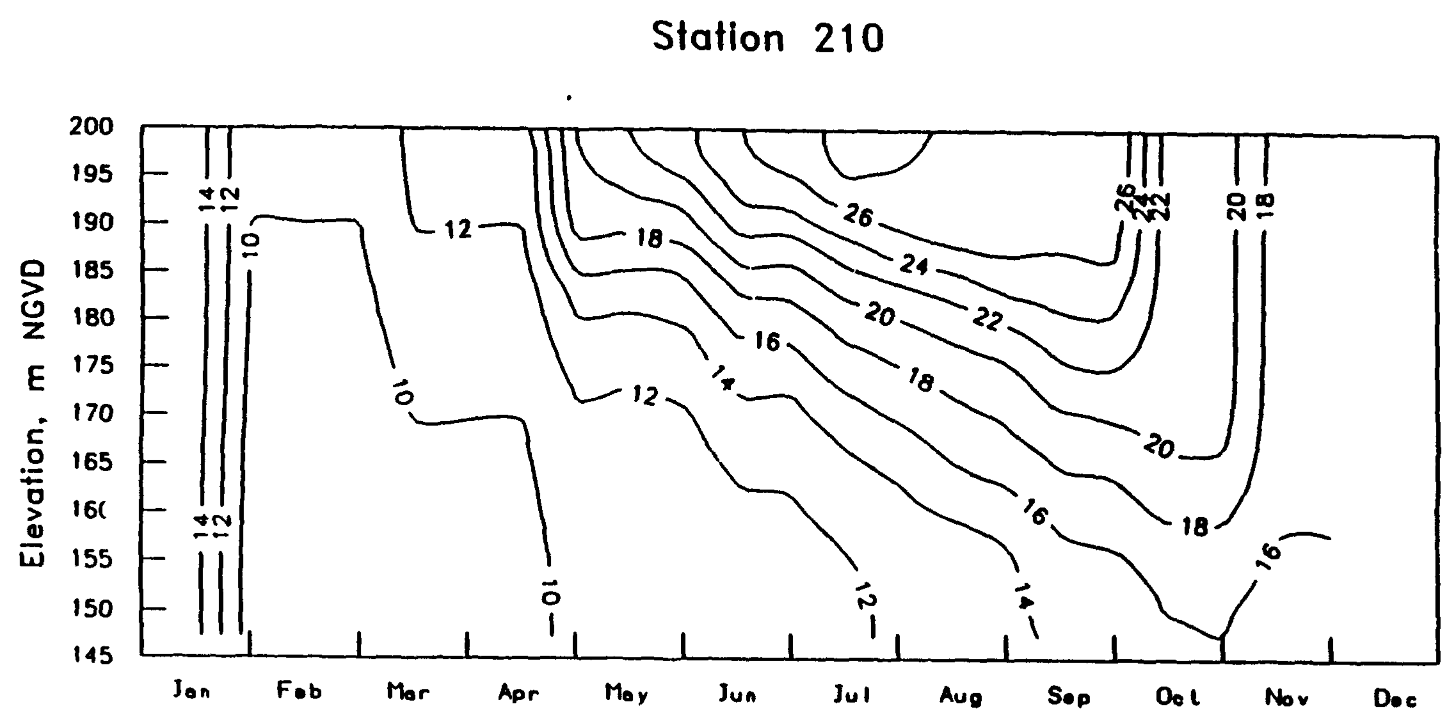


Figure 5. Temporal and vertical changes in temperature (°C) in the forebay of Hartwell Lake (Station 210)

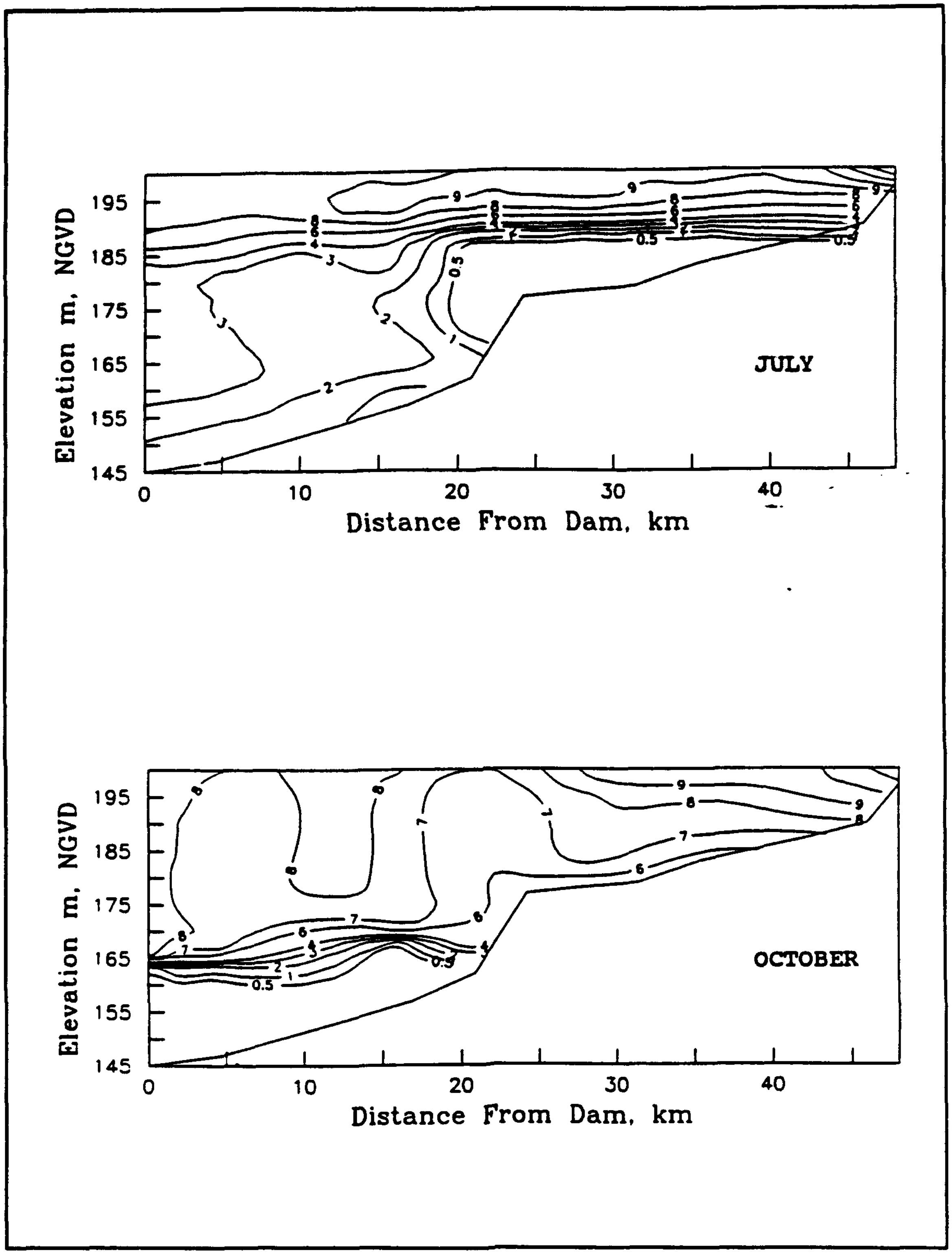


Figure 6. Patterns of spatial distribution of dissolved oxygen concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

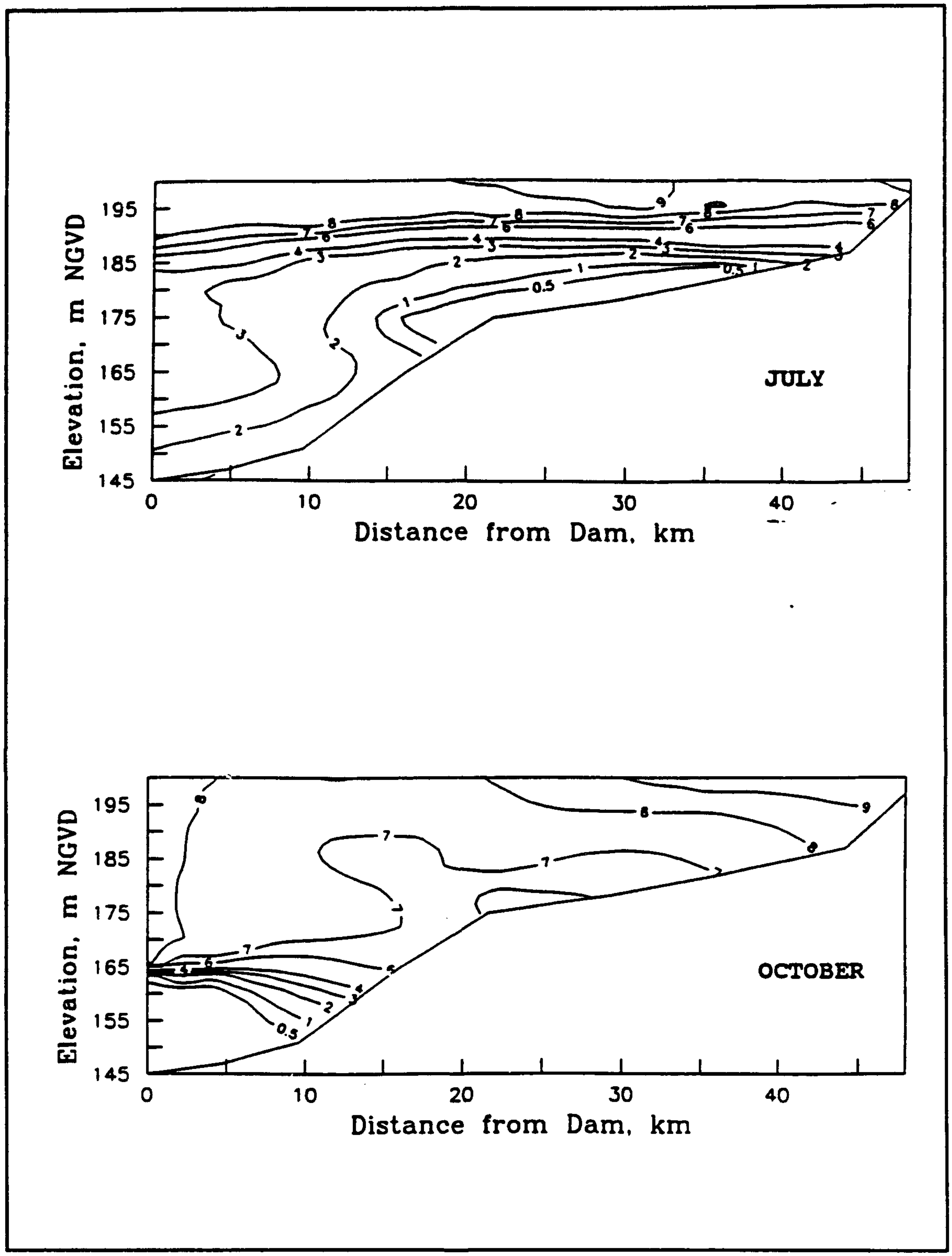


Figure 7. Patterns of spatial distribution of dissolved oxygen concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

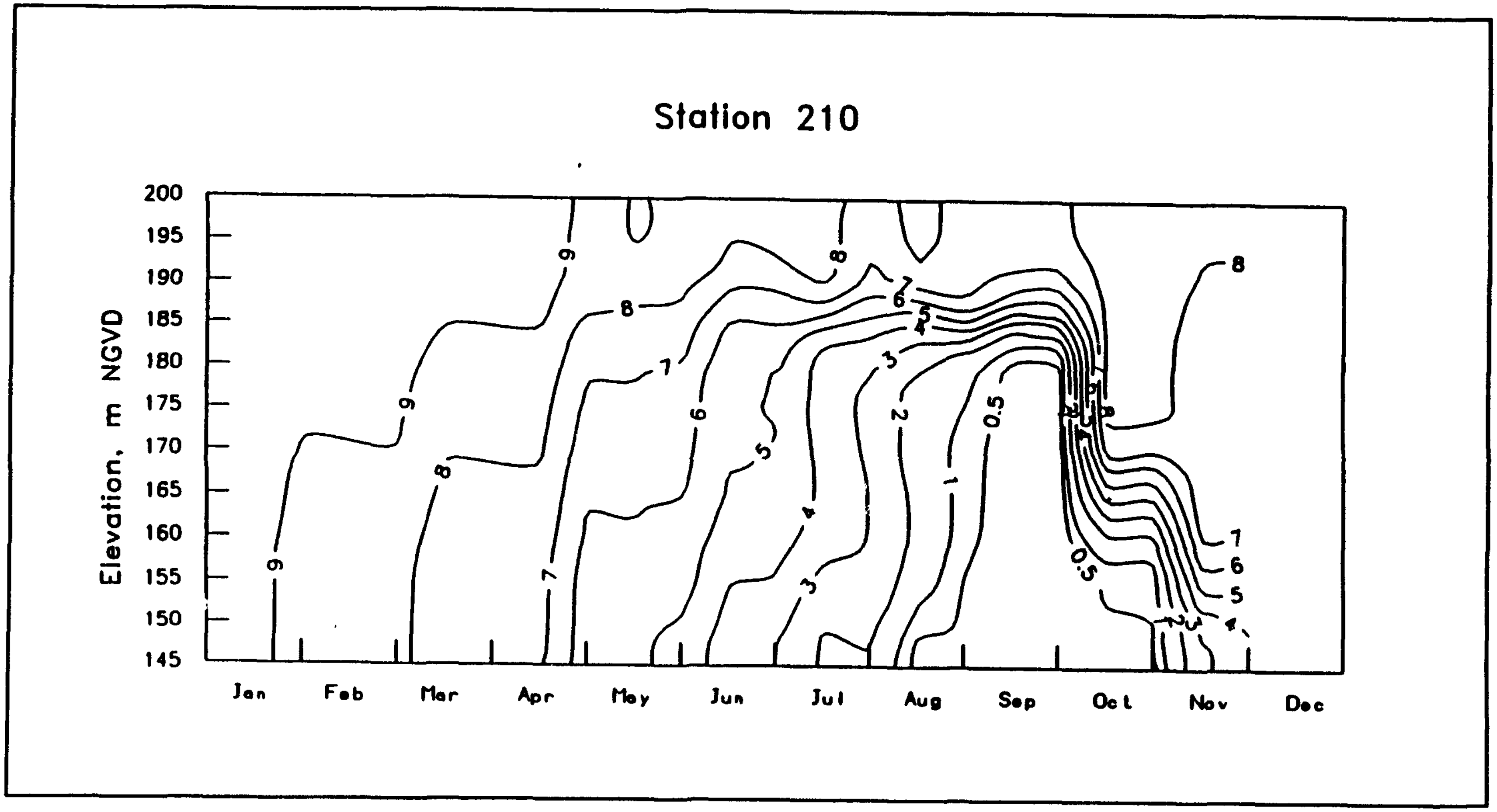


Figure 8. Temporal and vertical changes in dissolved oxygen (°C) in the forebay of Hartwell Lake (Station 210)

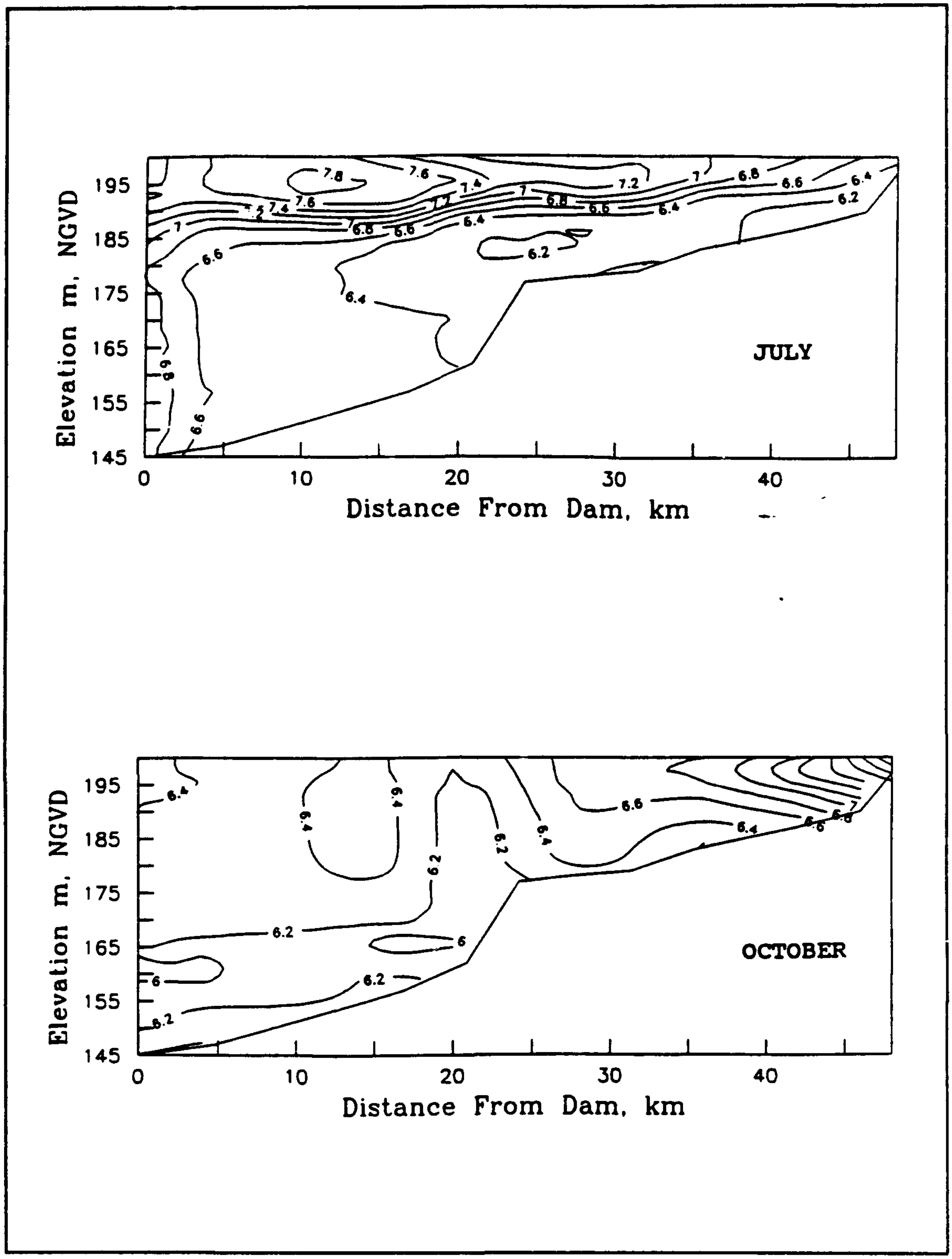


Figure 9. Patterns of spatial distribution of ph (ph units) from Hartwell Dam to upper Seneca River, July and October 1991

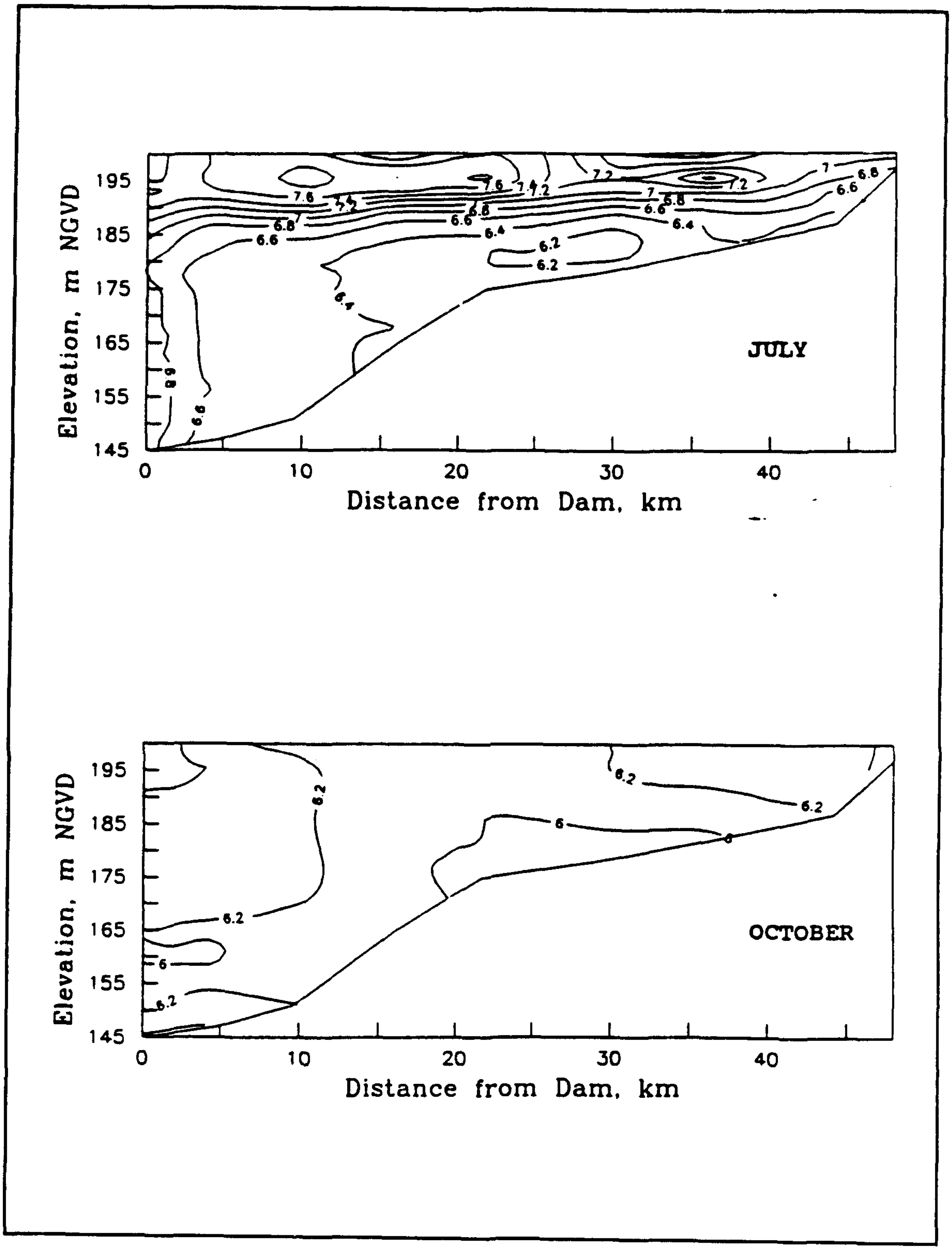


Figure 10. Patterns of spatial distribution of ph (ph units) from Hartwell Dam to upper Tugaloo River, July and October 1991

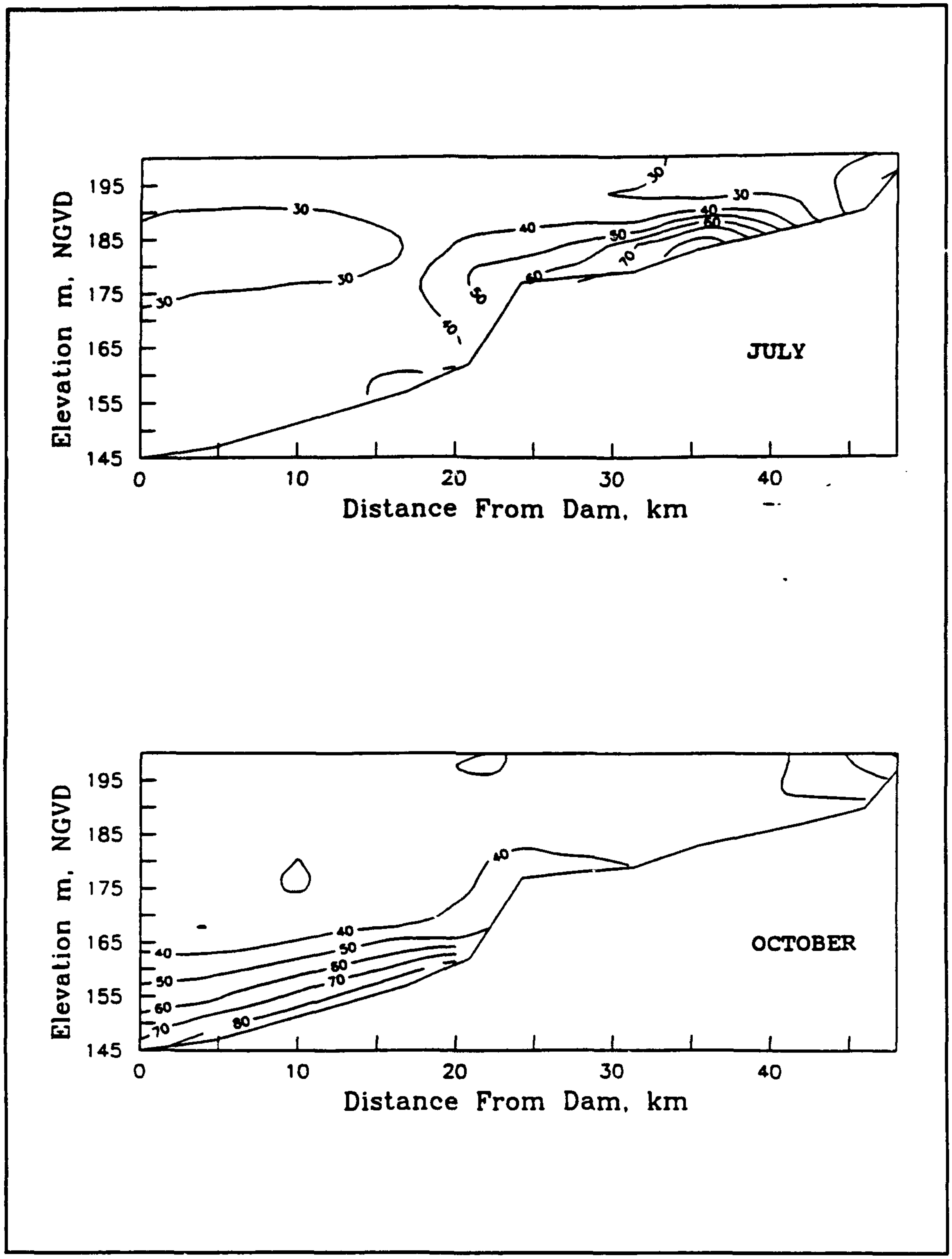


Figure 11. Patterns of spatial distribution of specific conductance (µS) from Hartwell Dam to upper Seneca River, July and October 1991

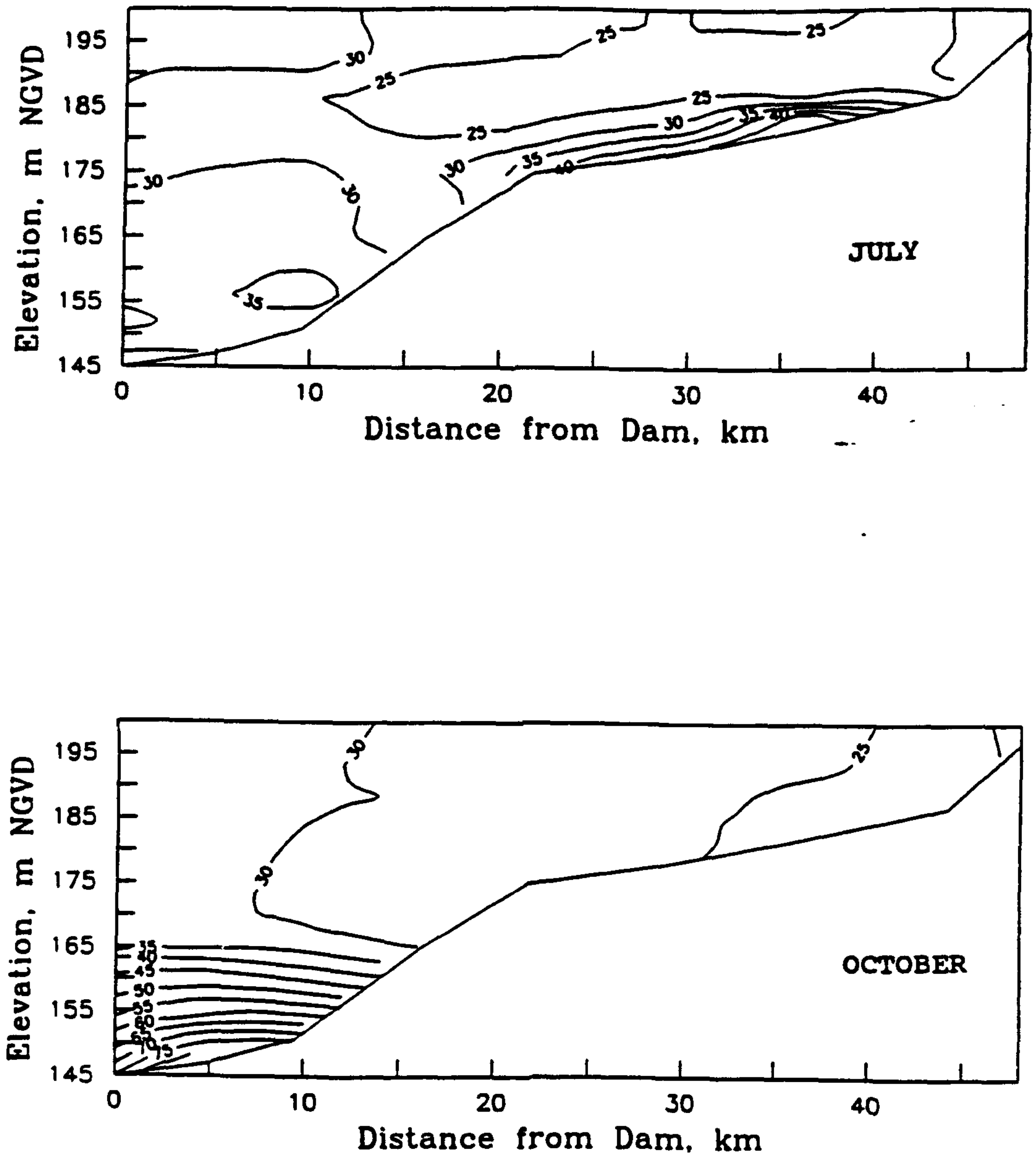


Figure 12. Patterns of spatial distribution of specific conductance (µS) from Hartwell Dam to upper Tugaloo River, July and October 1991

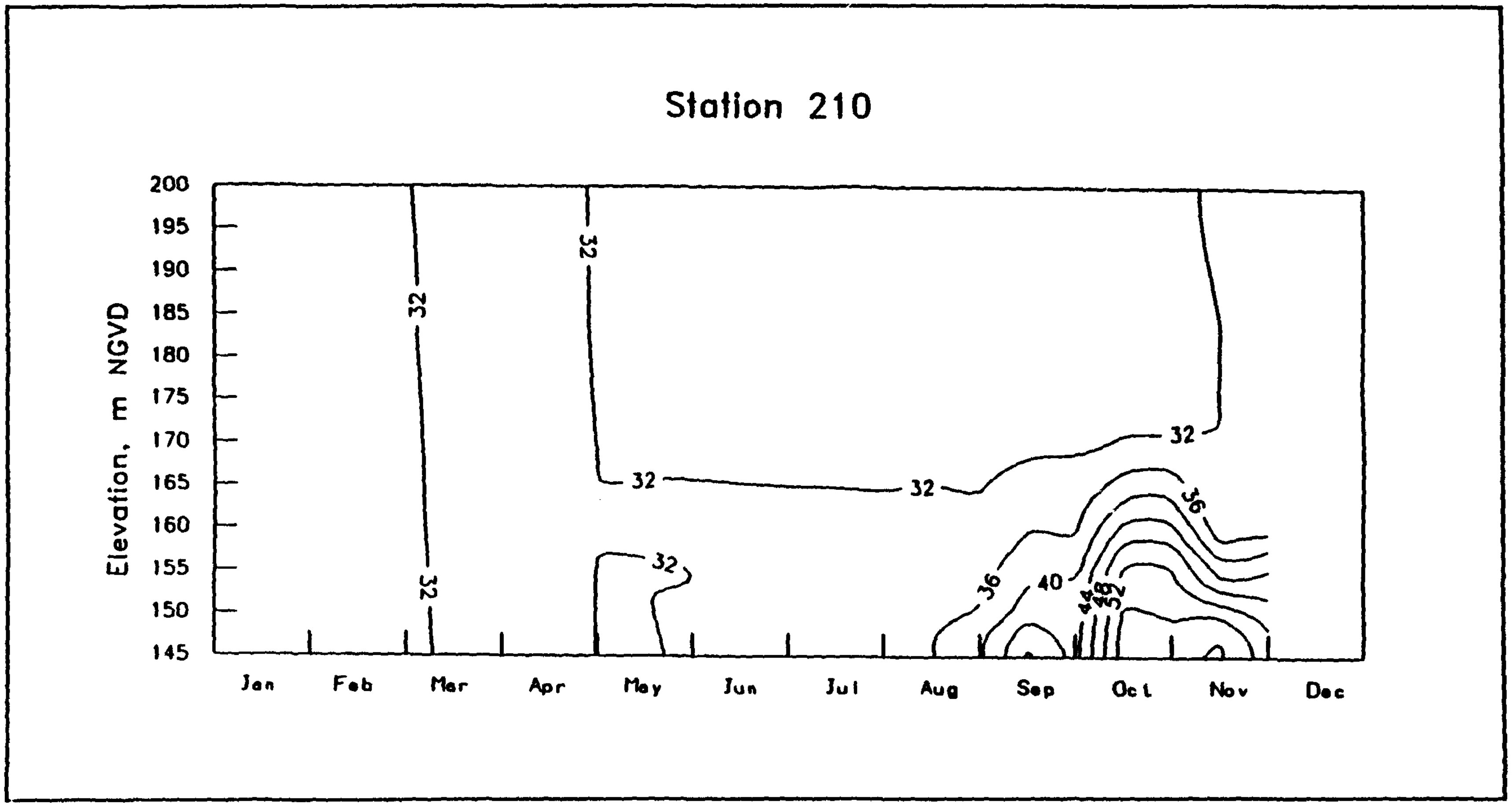


Figure 13. Temporal and vertical changes in specific conductance (µS) in the forebay of Hartwell Lake (Station 210)

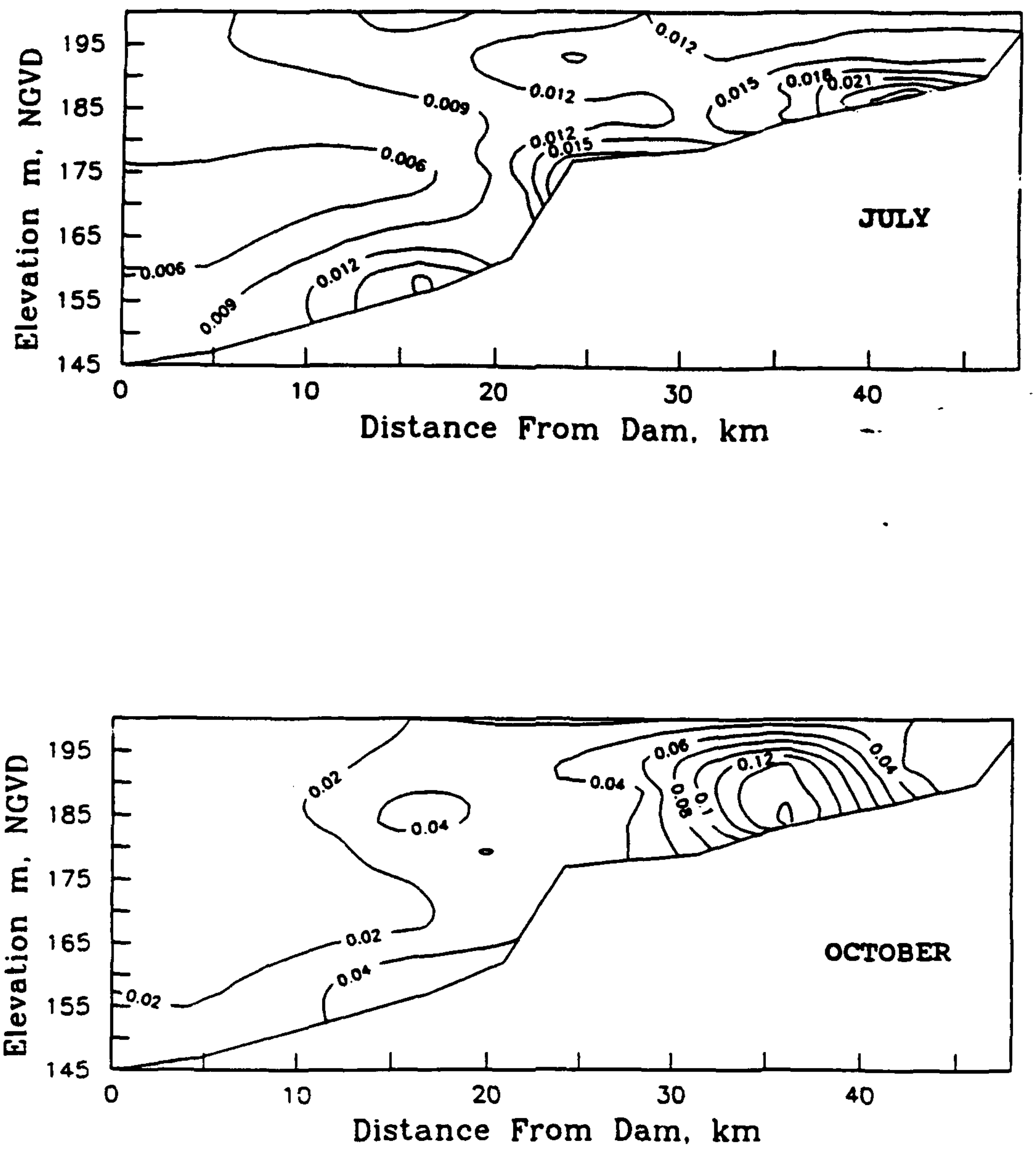


Figure 14. Patterns of spatial distribution of total phosphorus concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

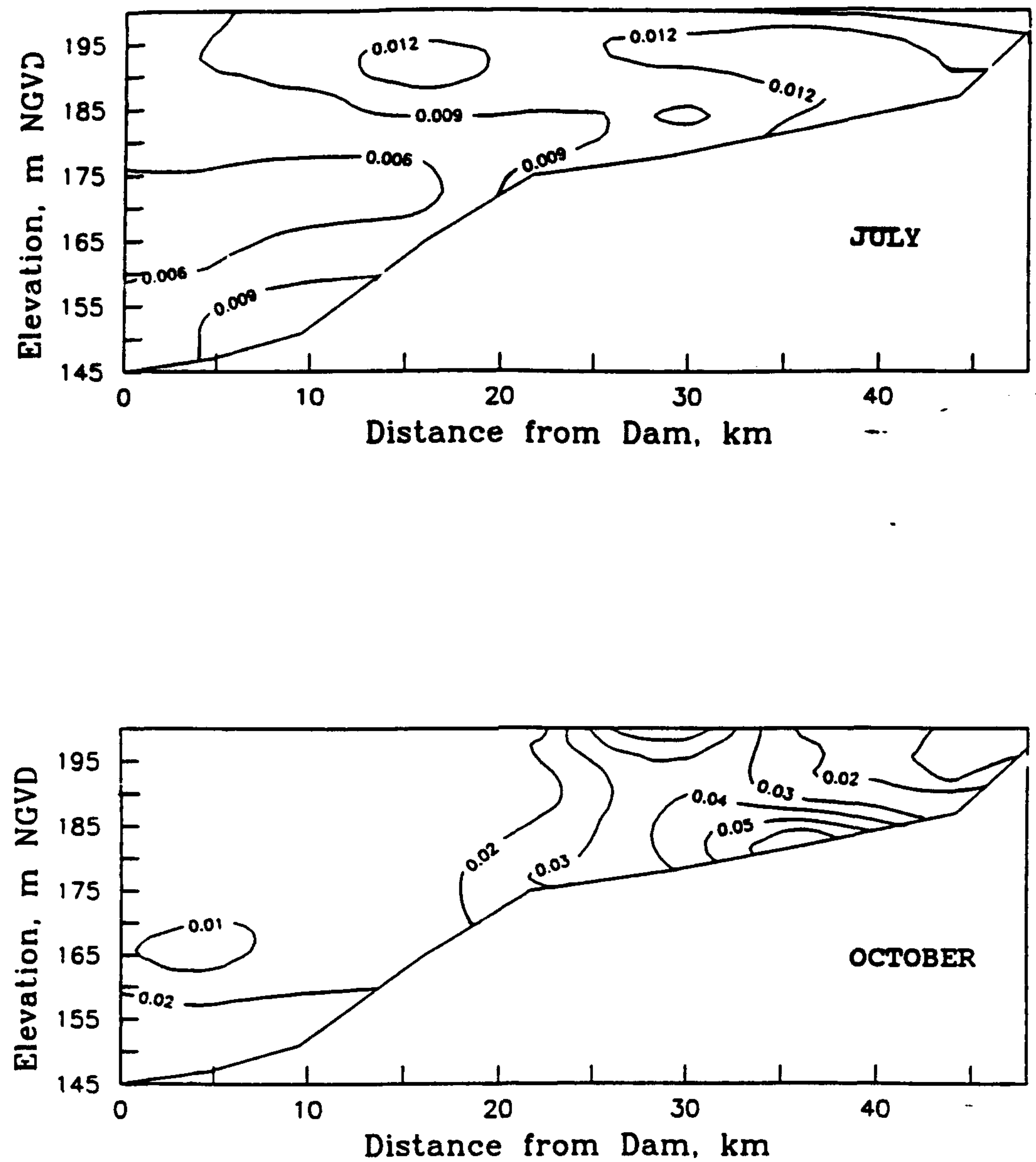


Figure 15. Patterns of spatial distribution of total phosphorus concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

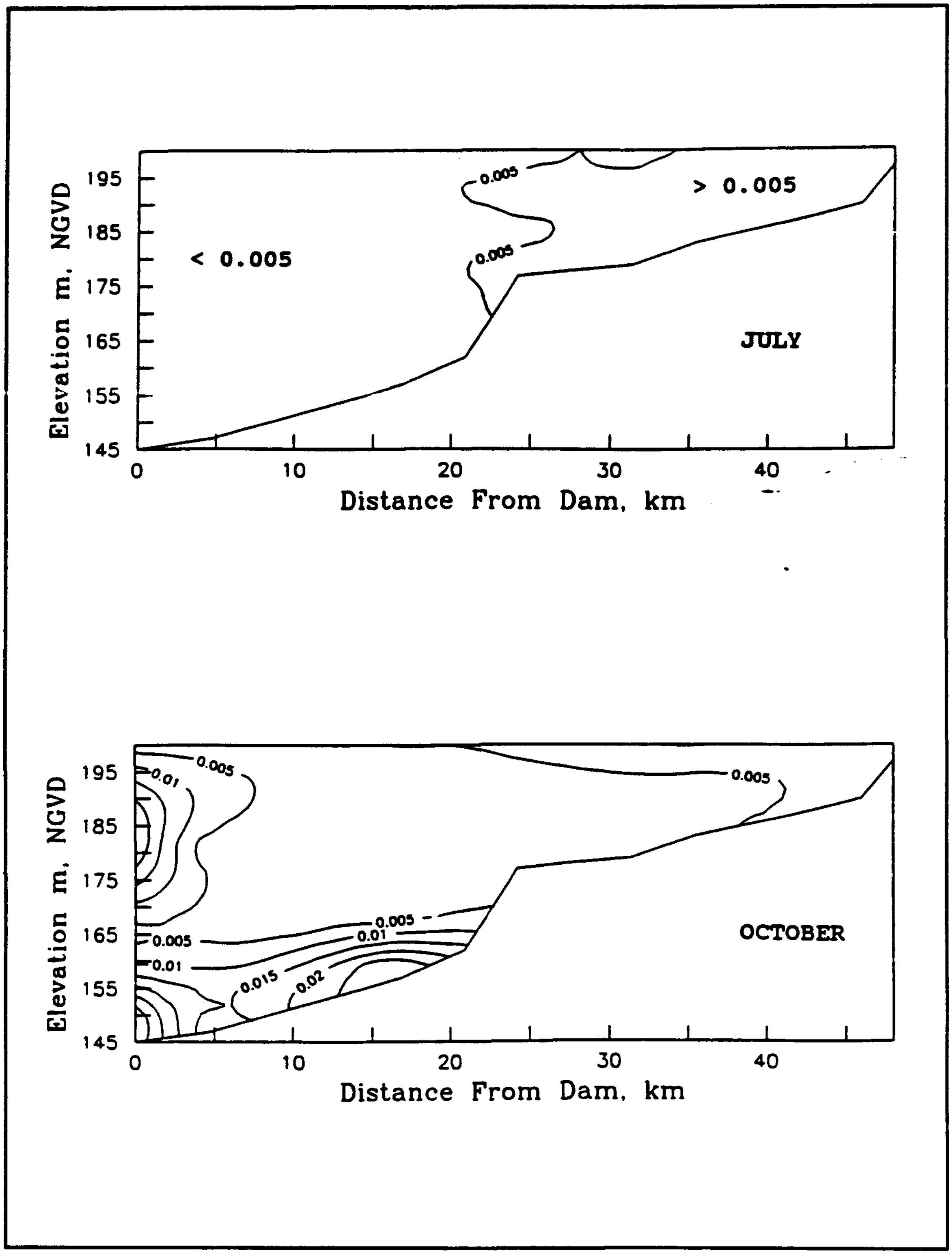


Figure 16. Patterns of spatial distribution of total soluble phosphorus concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

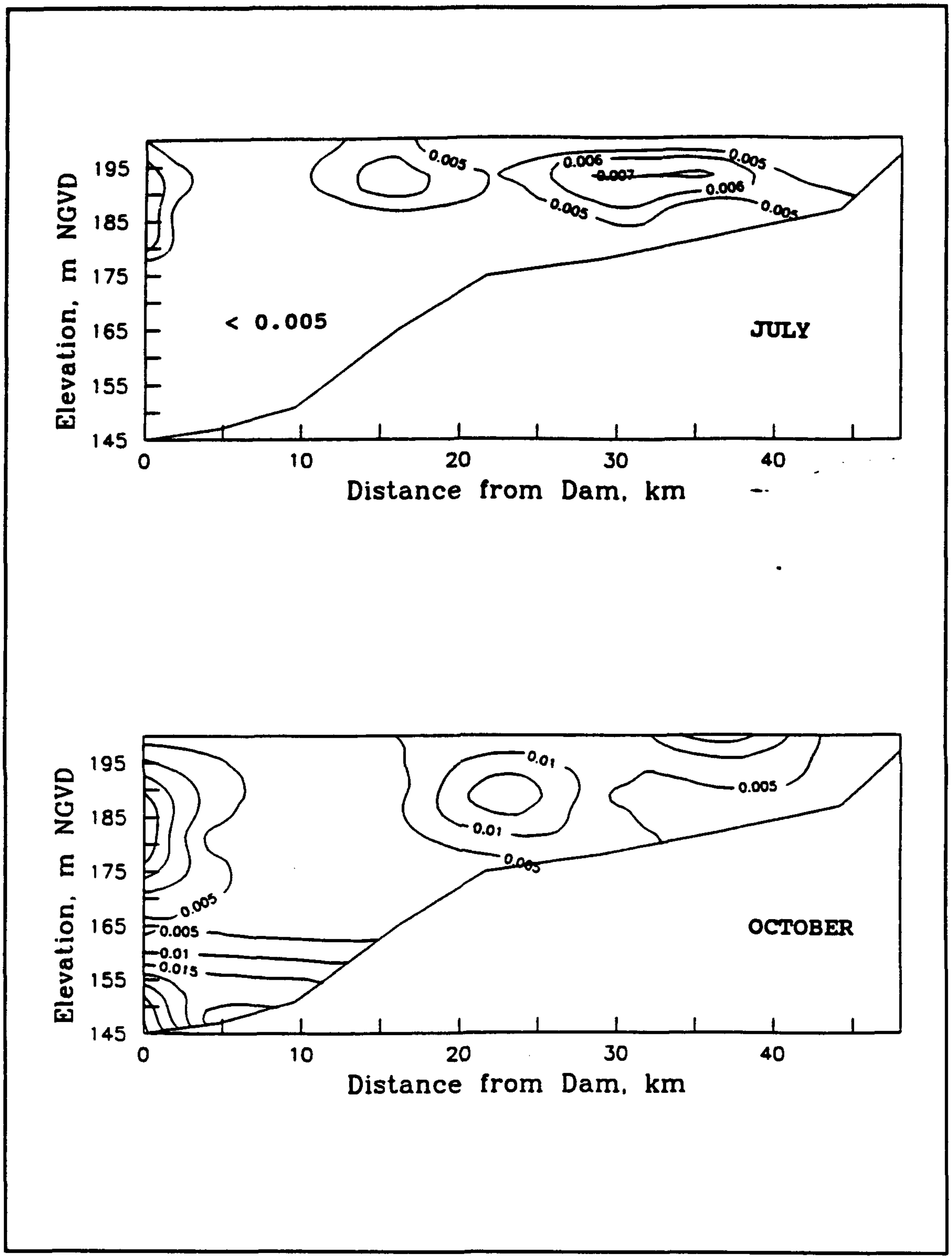


Figure 17. Patterns of spatial distribution of total soluble phosphorus concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

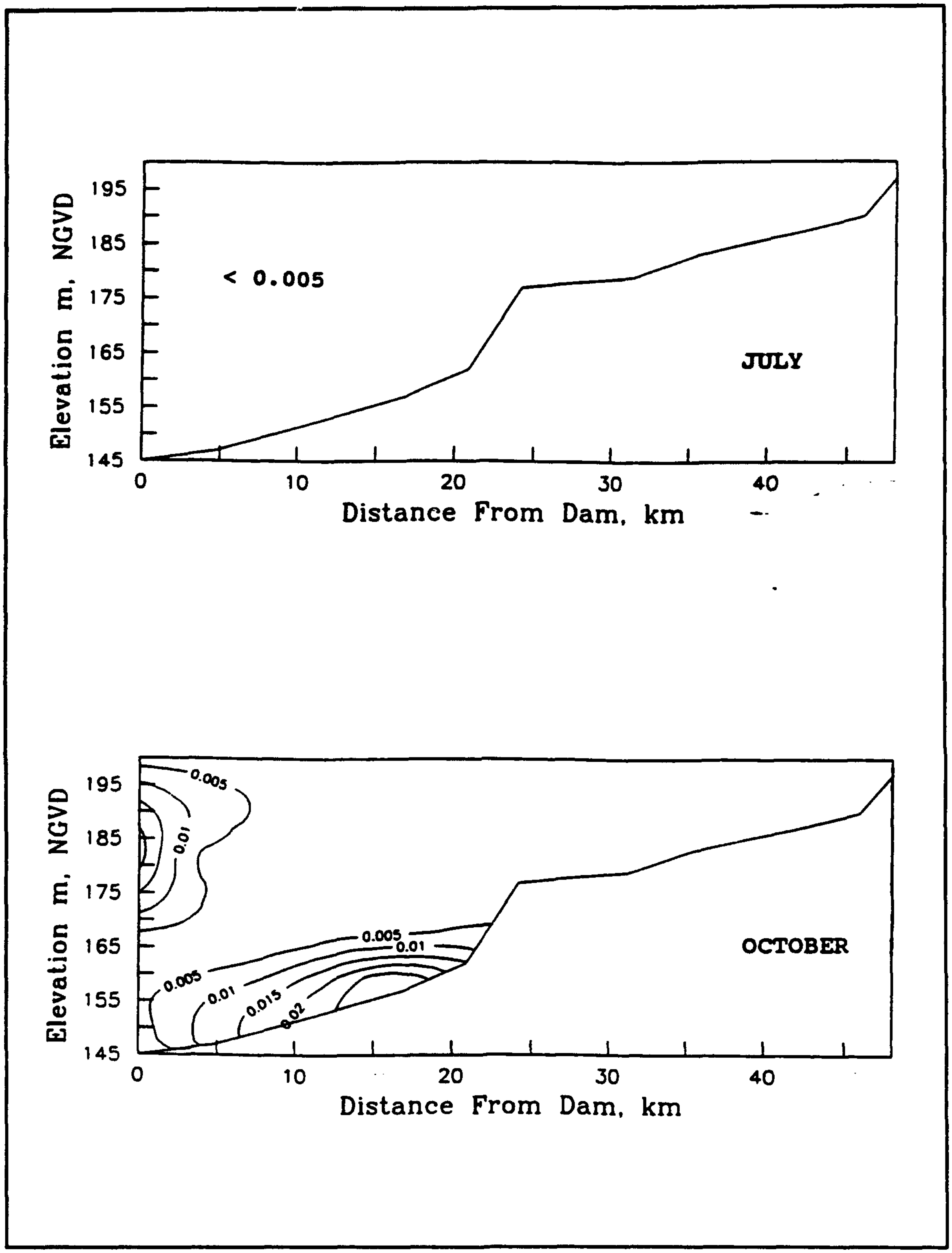


Figure 18. Patterns of spatial distribution of soluble reactive phosphorus concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

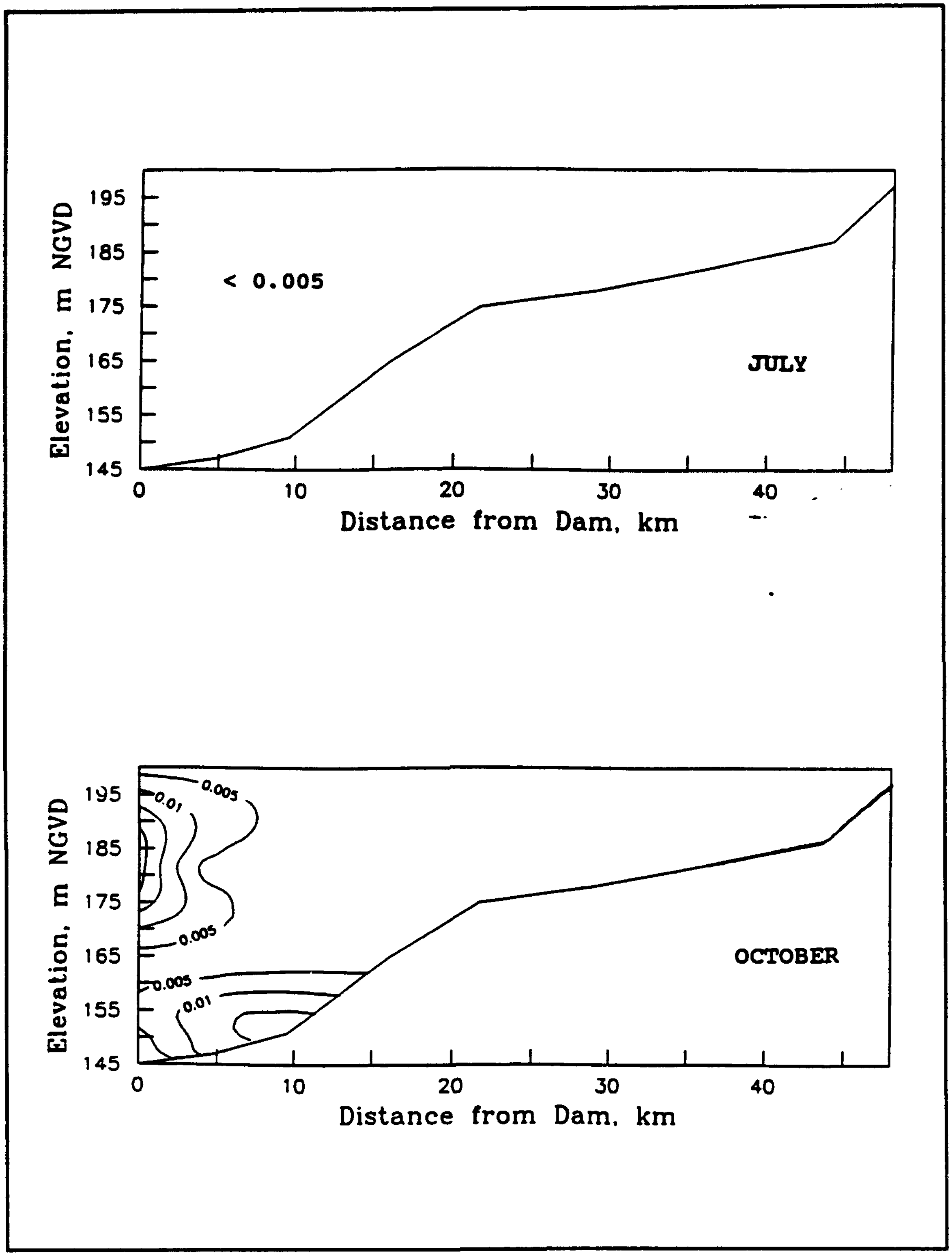


Figure 19. Patterns of spatial distribution of soluble reactive phosphorus concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

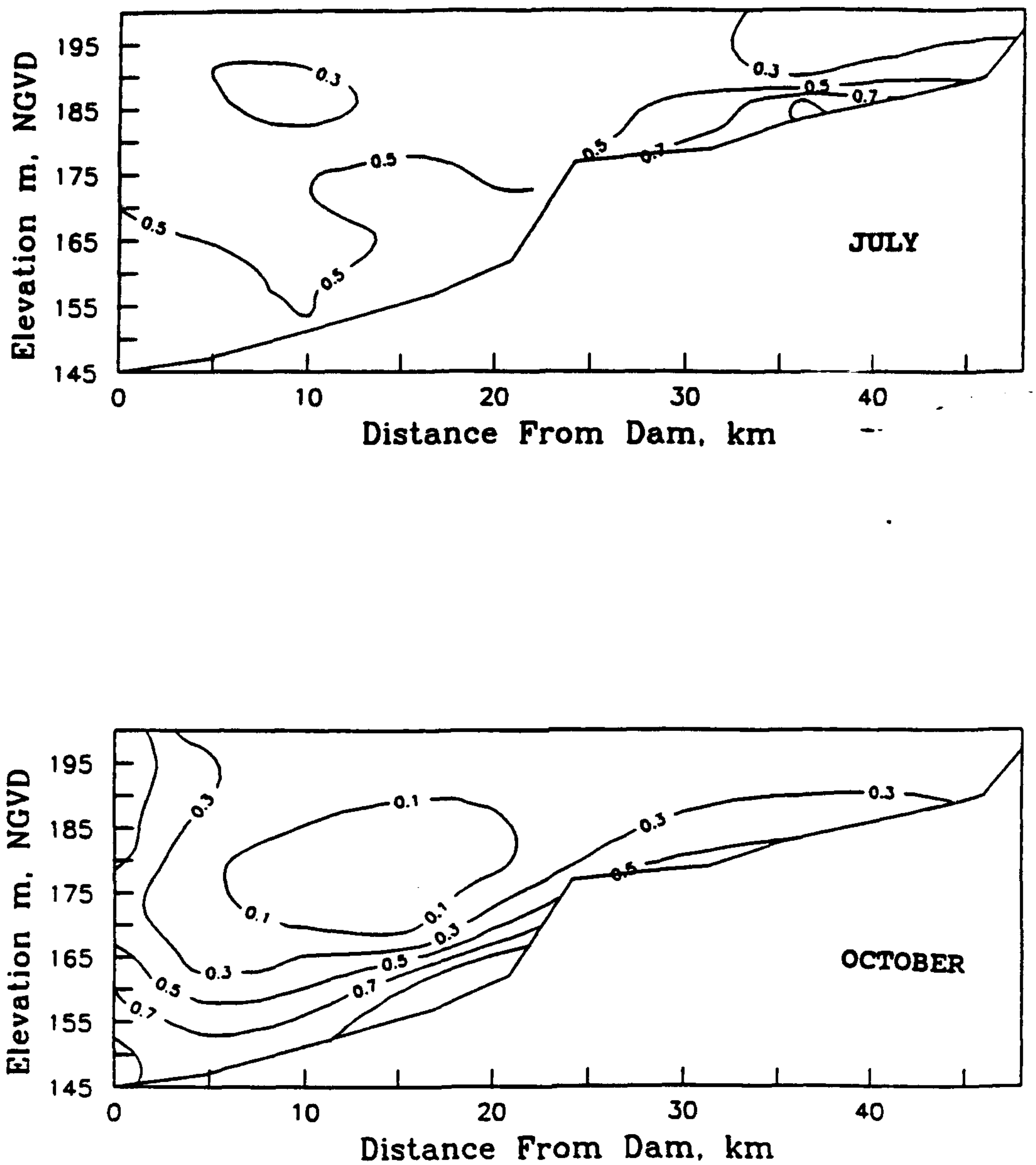
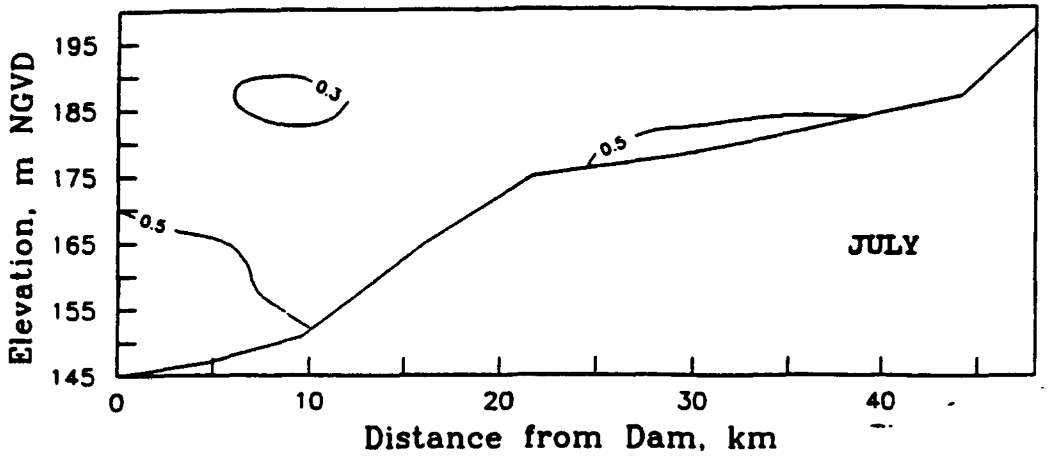


Figure 20. Patterns of spatial distribution of total nitrogen concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991



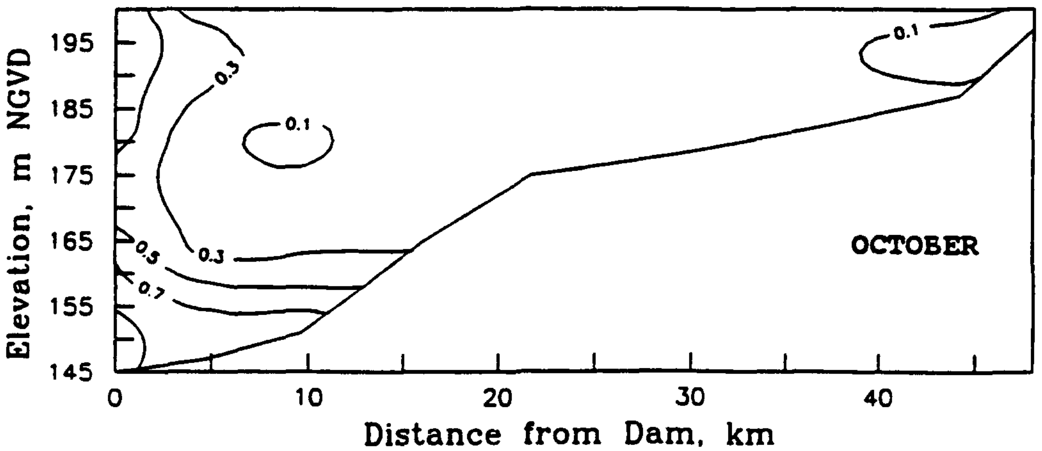


Figure 21. Patterns of spatial distribution of total nitrogen concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

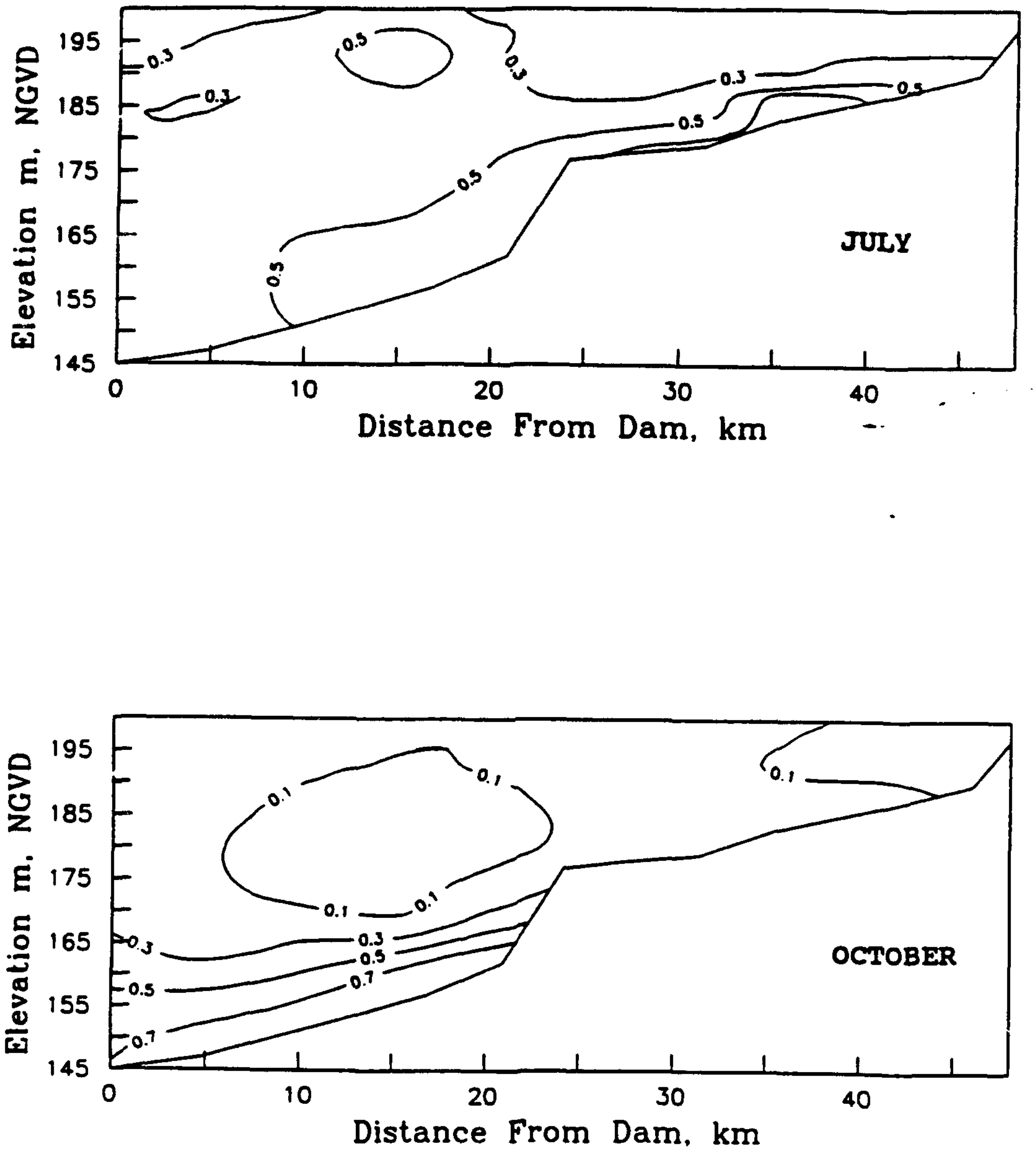


Figure 22. Patterns of spatial distribution of dissolved nitrogen concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

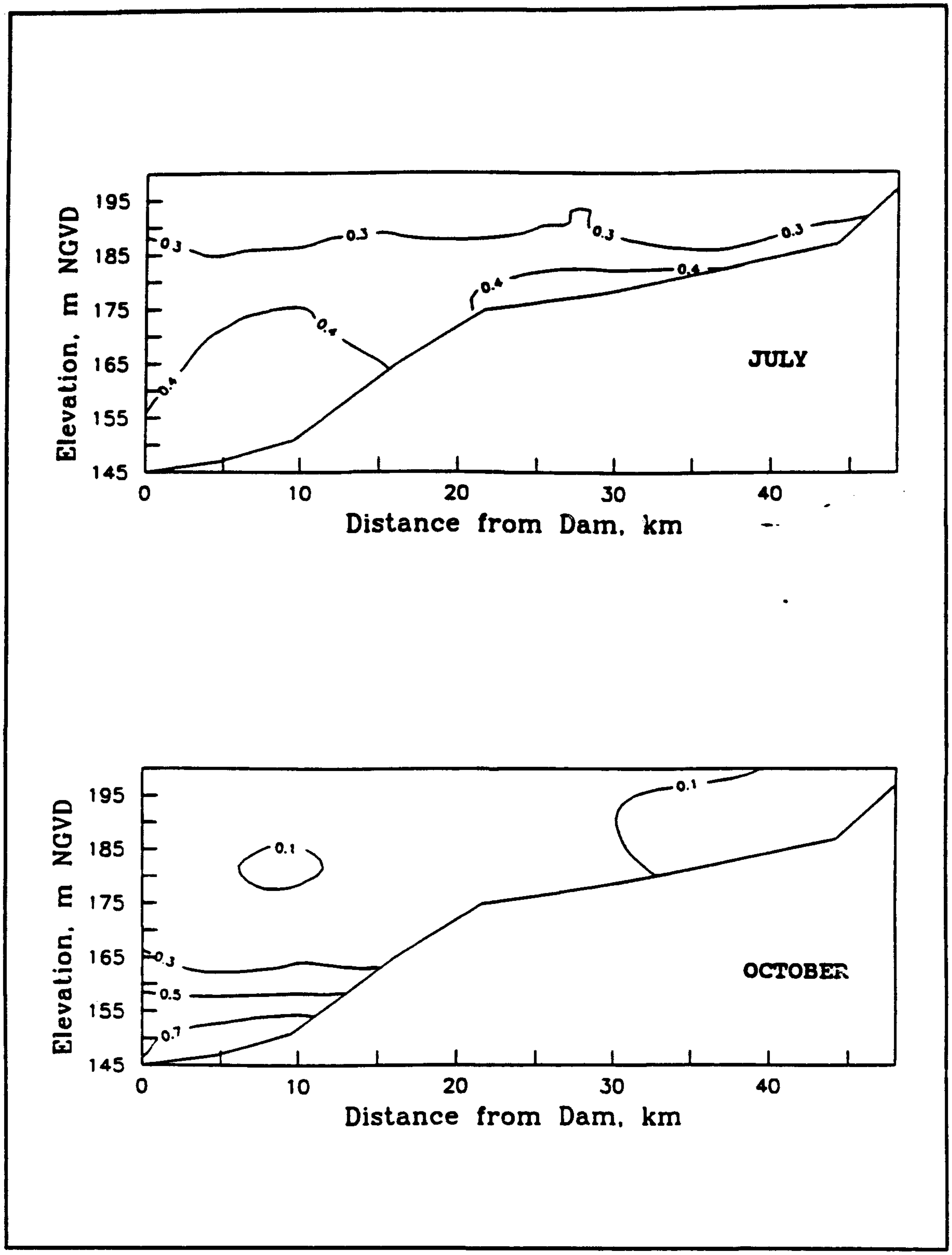


Figure 23. Patterns of spatial distribution of dissolved nitrogen concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

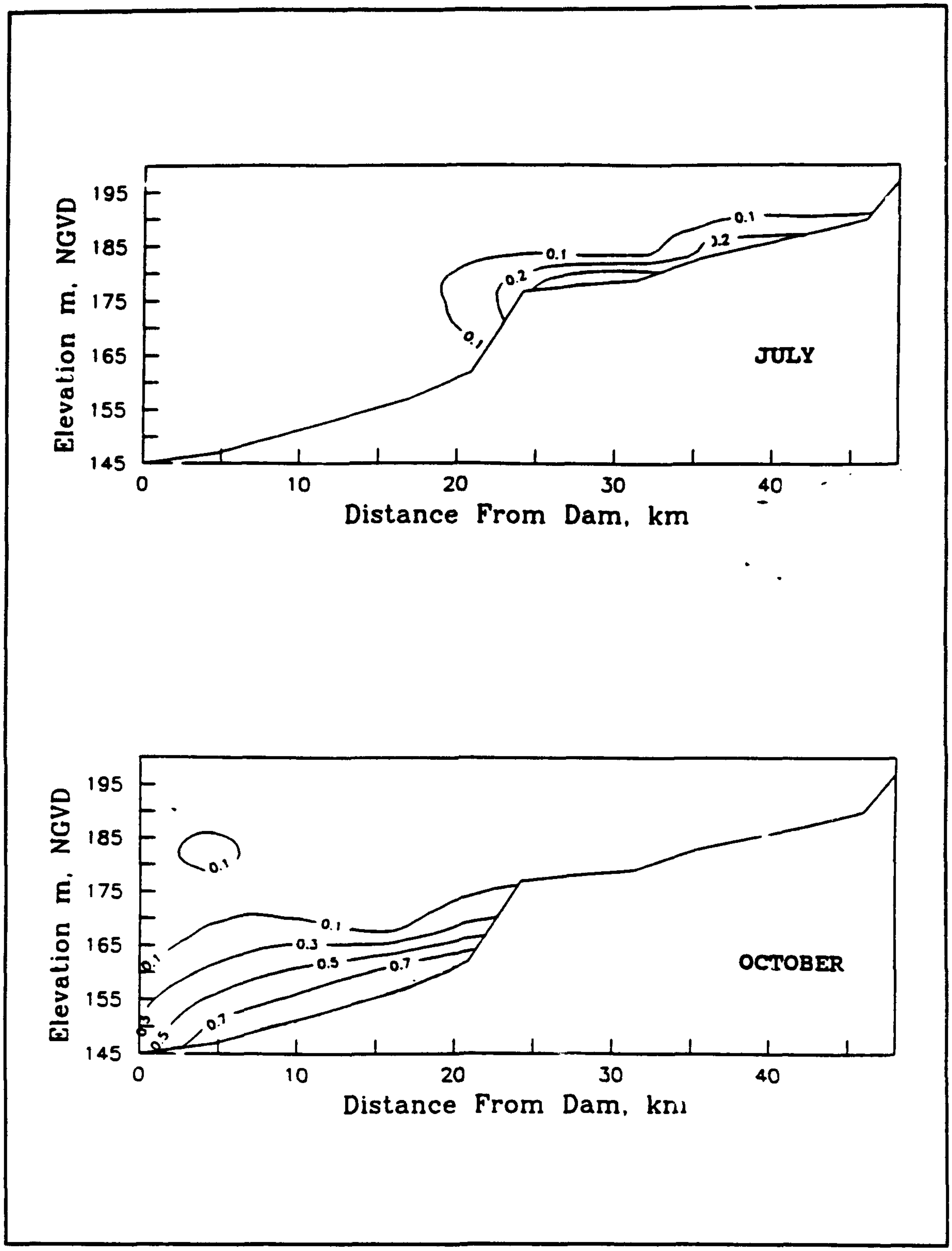


Figure 24. Patterns of spatial distribution of ammonia-nitrogen concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

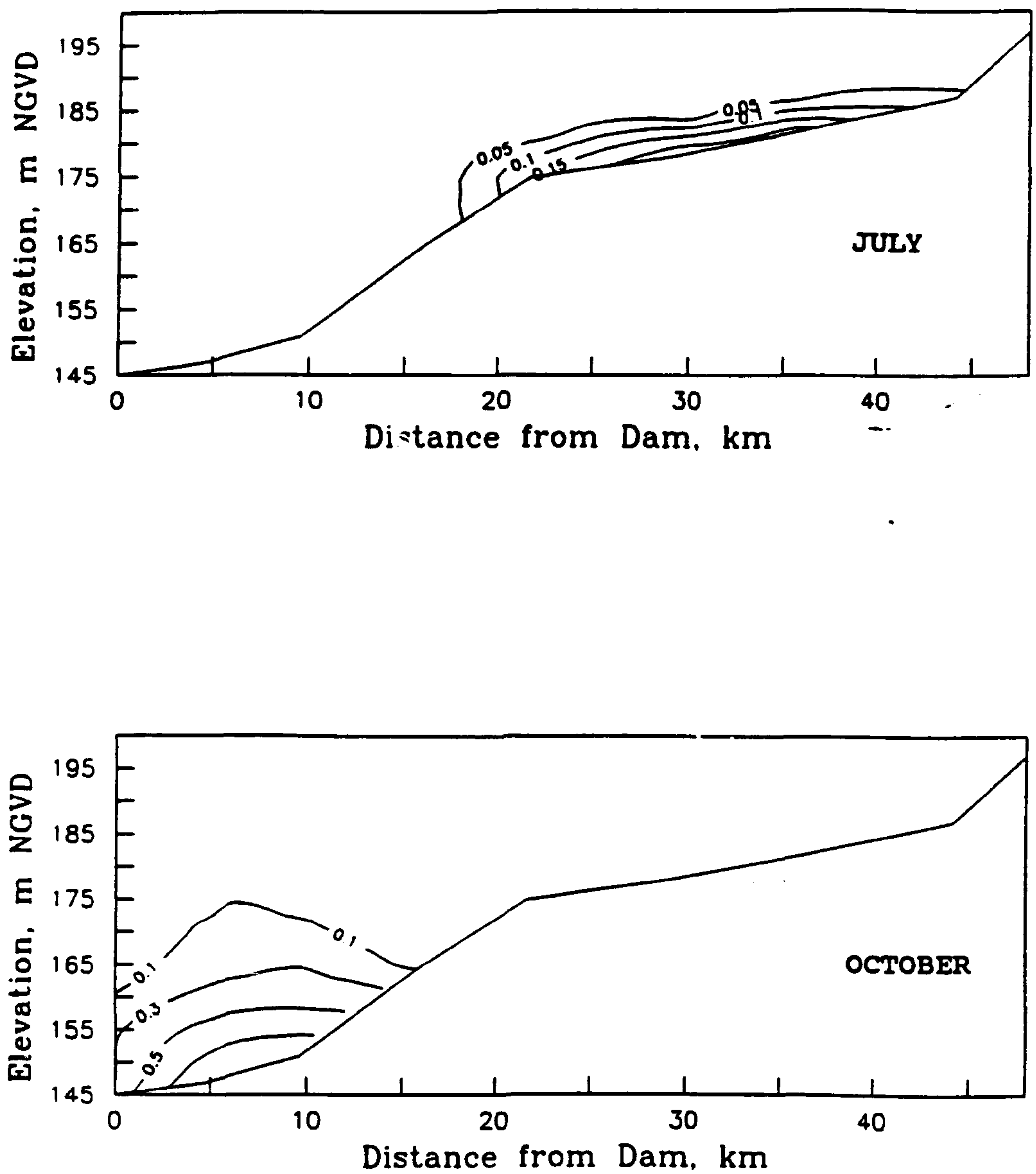
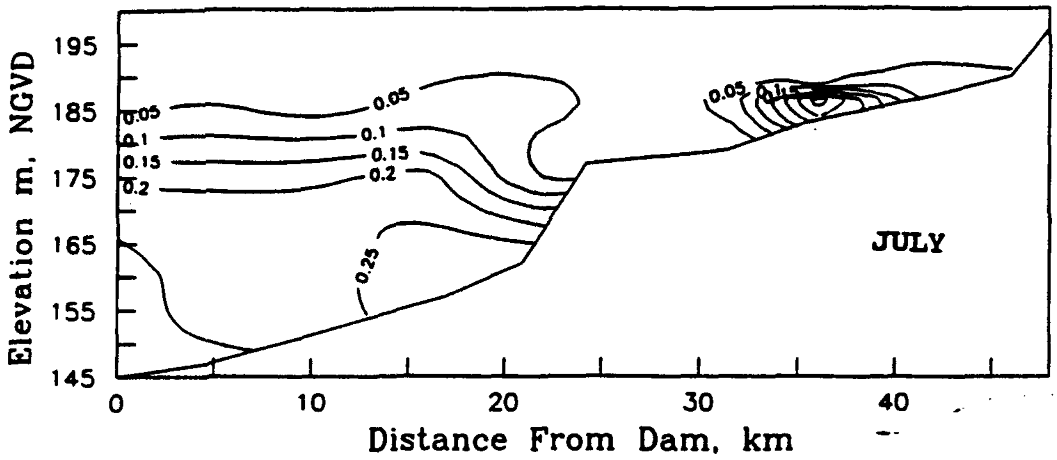


Figure 25. Patterns of spatial distribution of ammonia-nitrogen concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991



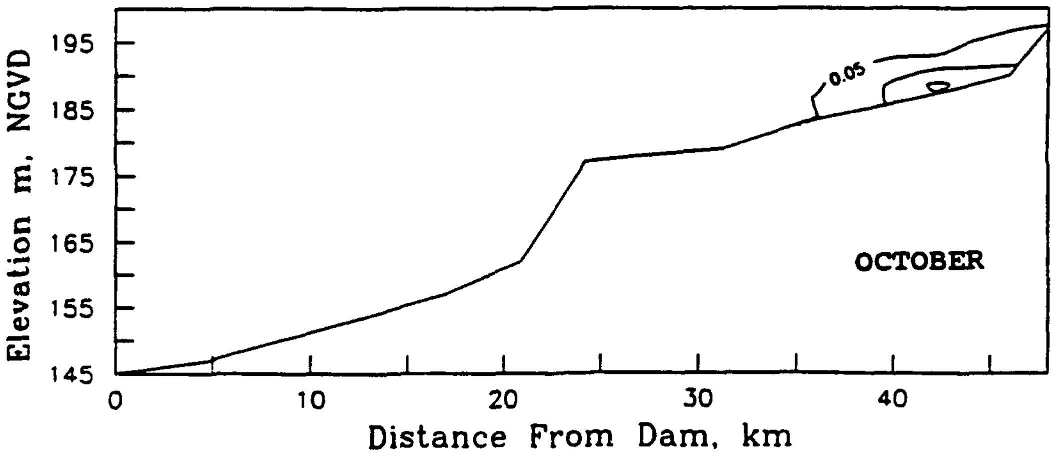
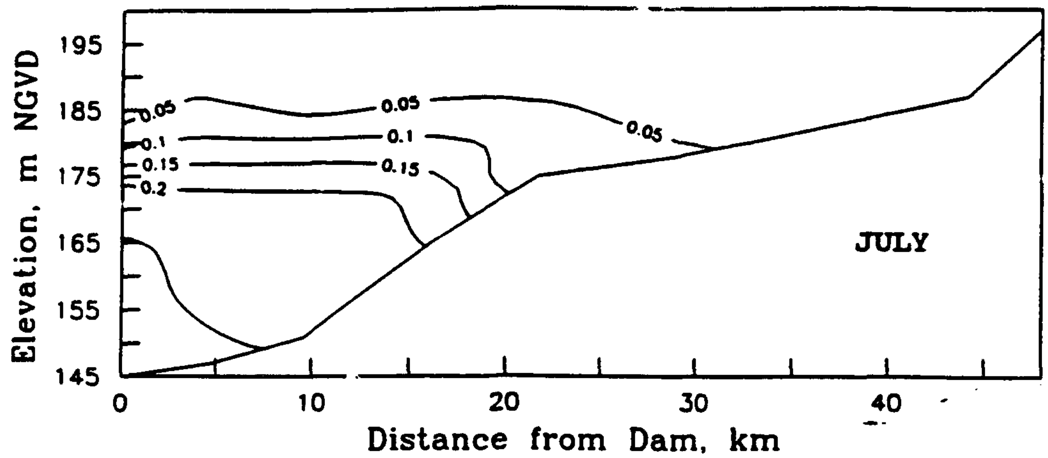


Figure 26. Patterns of spatial distribution of nitrate-nitrogen concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991



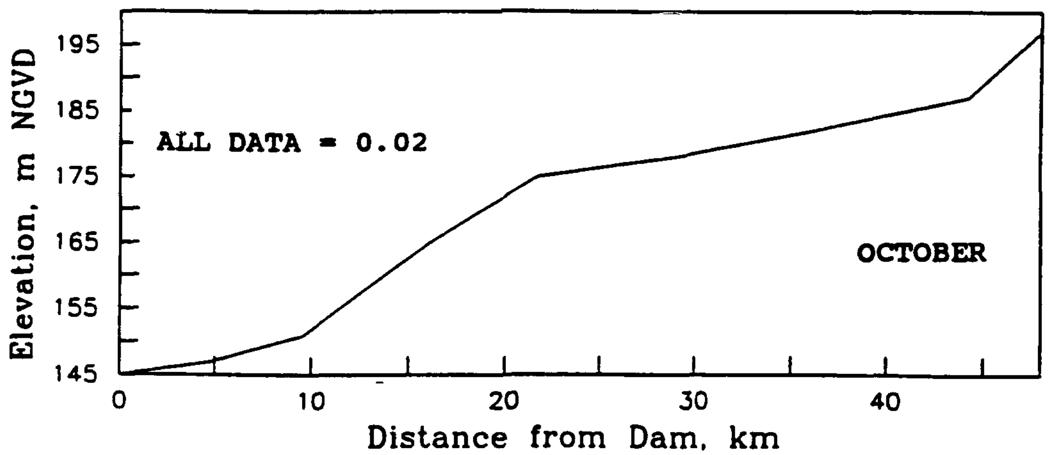


Figure 27. Patterns of spatial distribution of nitrate-nitrogen concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

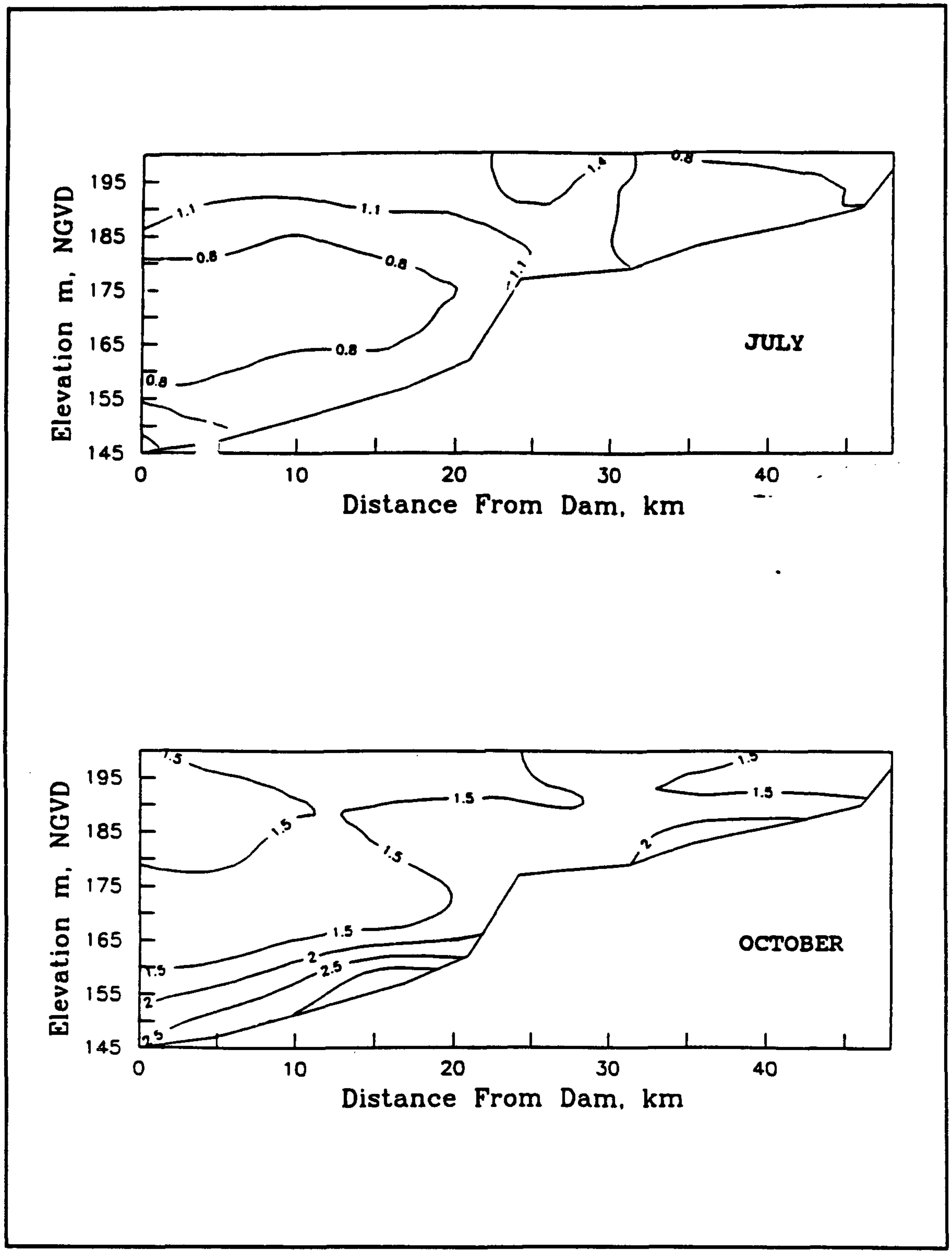


Figure 28. Patterns of spatial distribution of total organic carbon concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

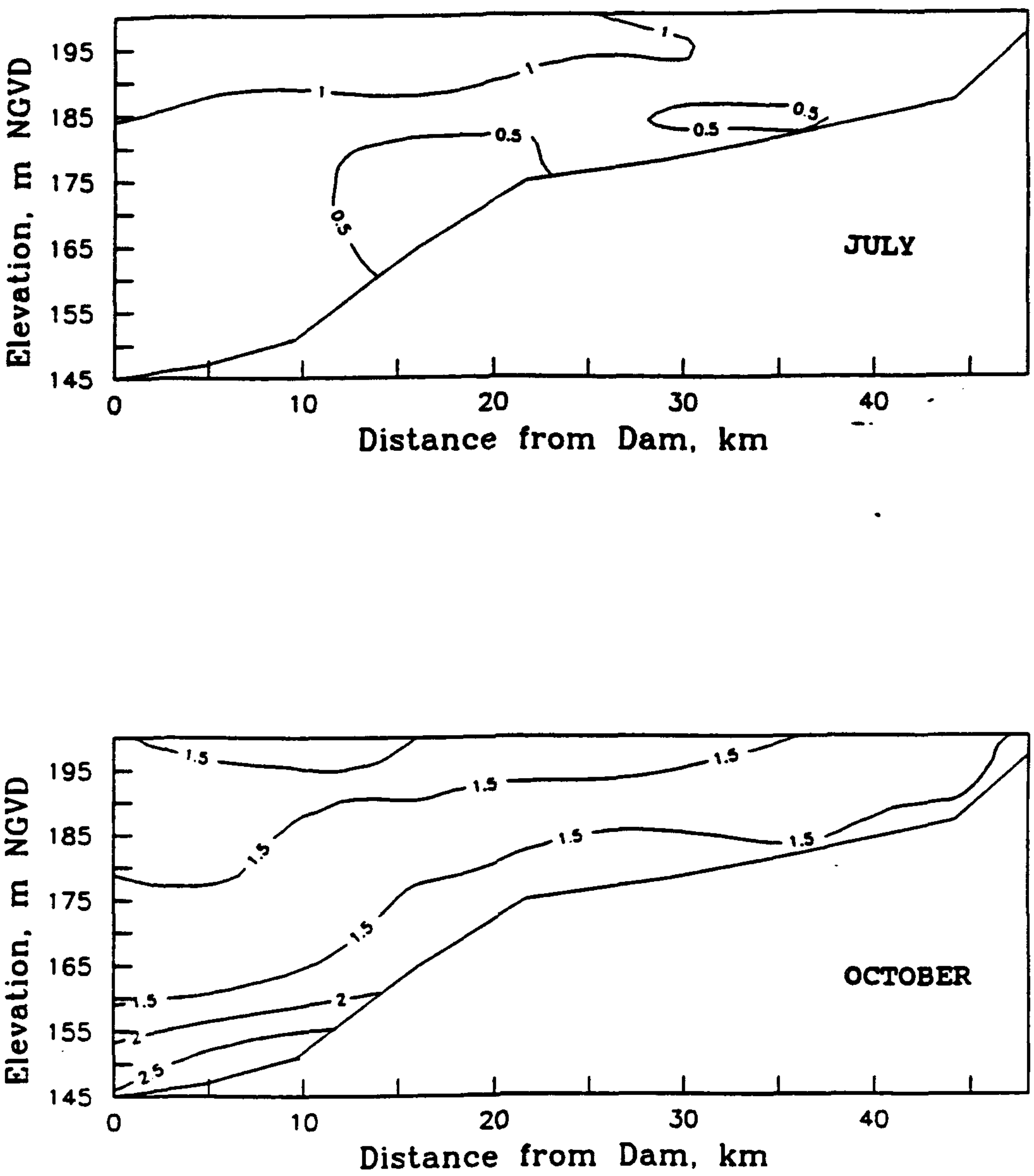


Figure 29. Patterns of spatial distribution of total organic carbon concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

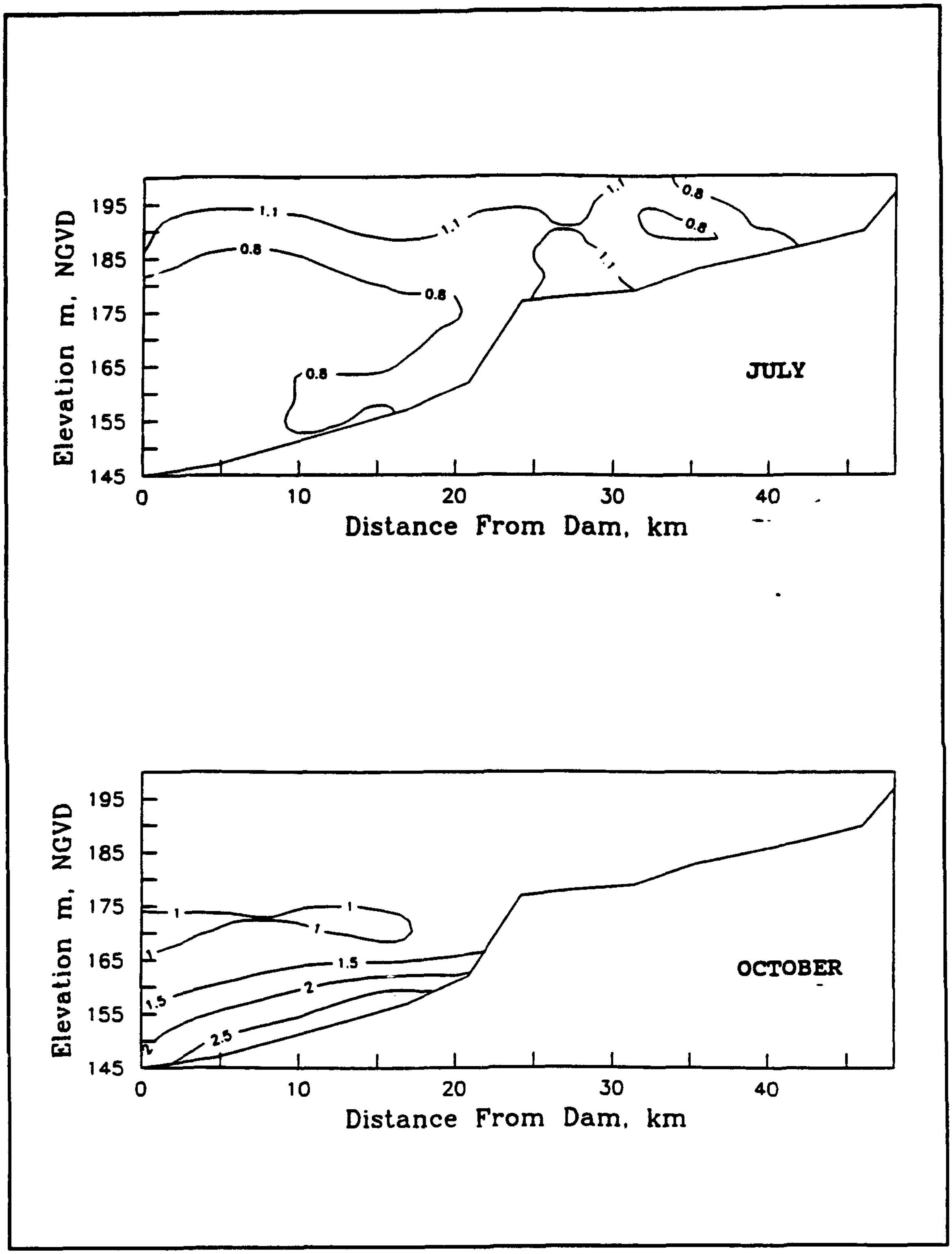


Figure 30. Patterns of spatial distribution of dissolved organic carbon concentrations (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

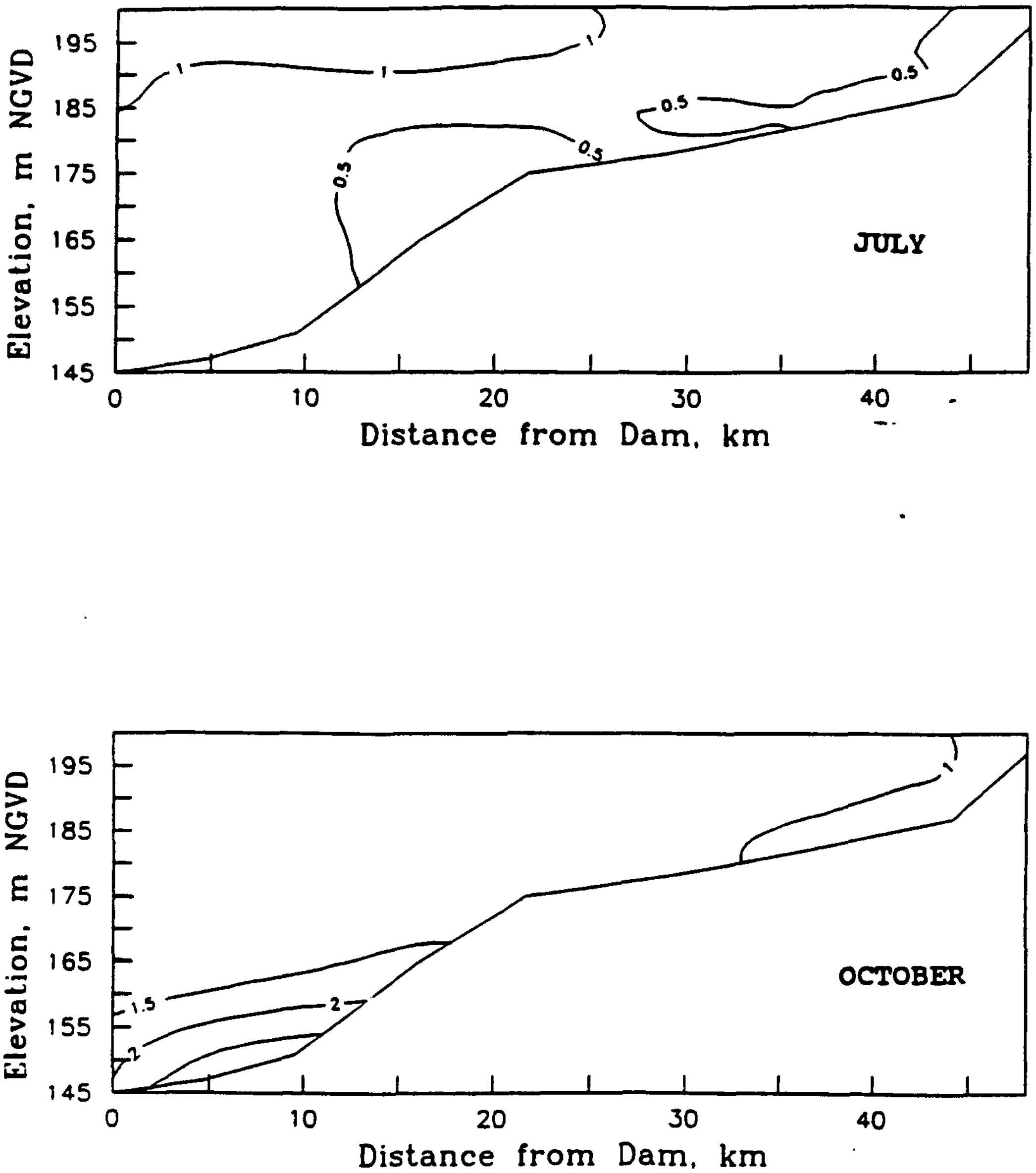


Figure 31. Patterns of spatial distribution of dissolved organic carbon concentrations (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

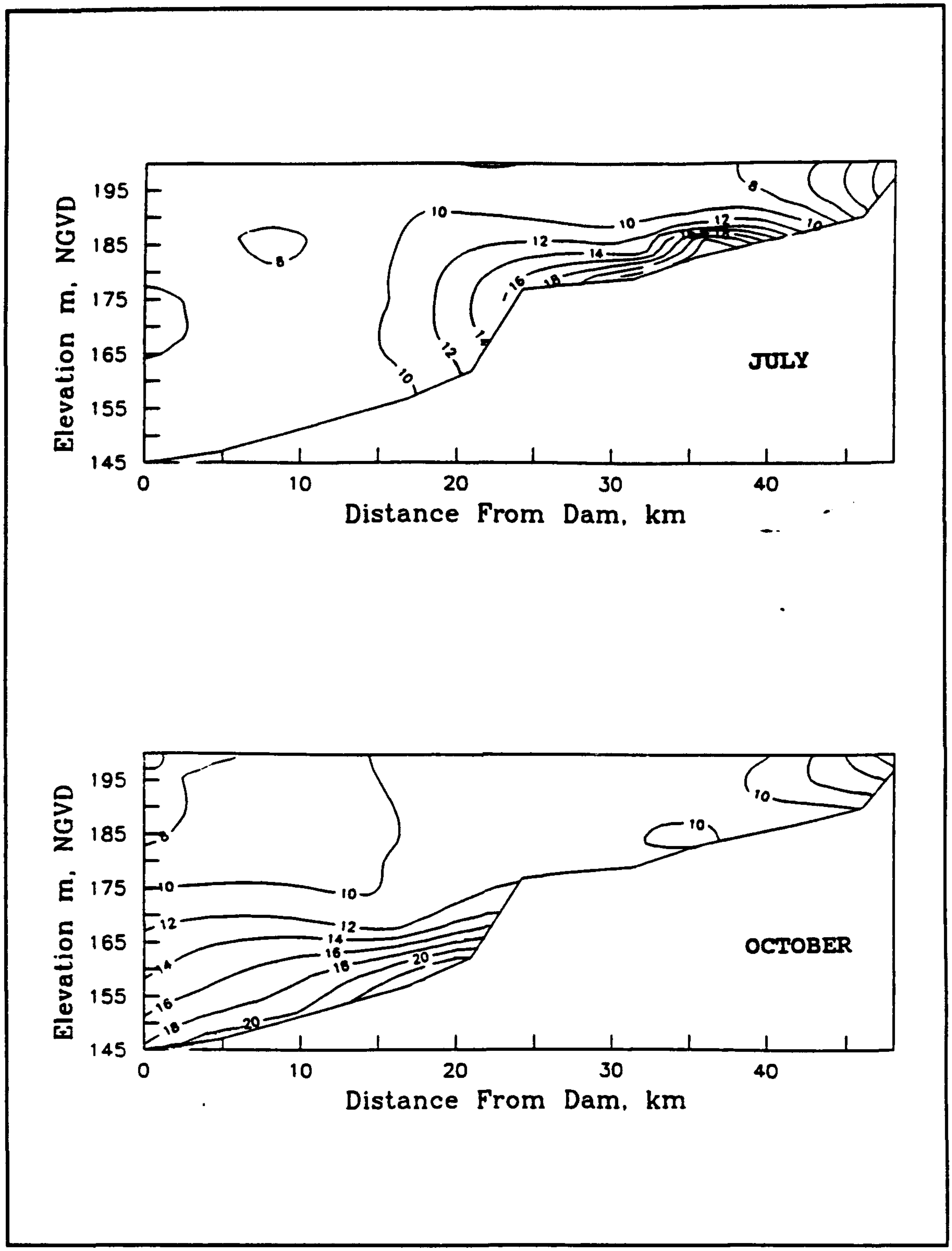


Figure 32. Patterns of spatial distribution of total alkalinity (mg/l) from Hartwell Dam to upper Seneca River, July and October 1991

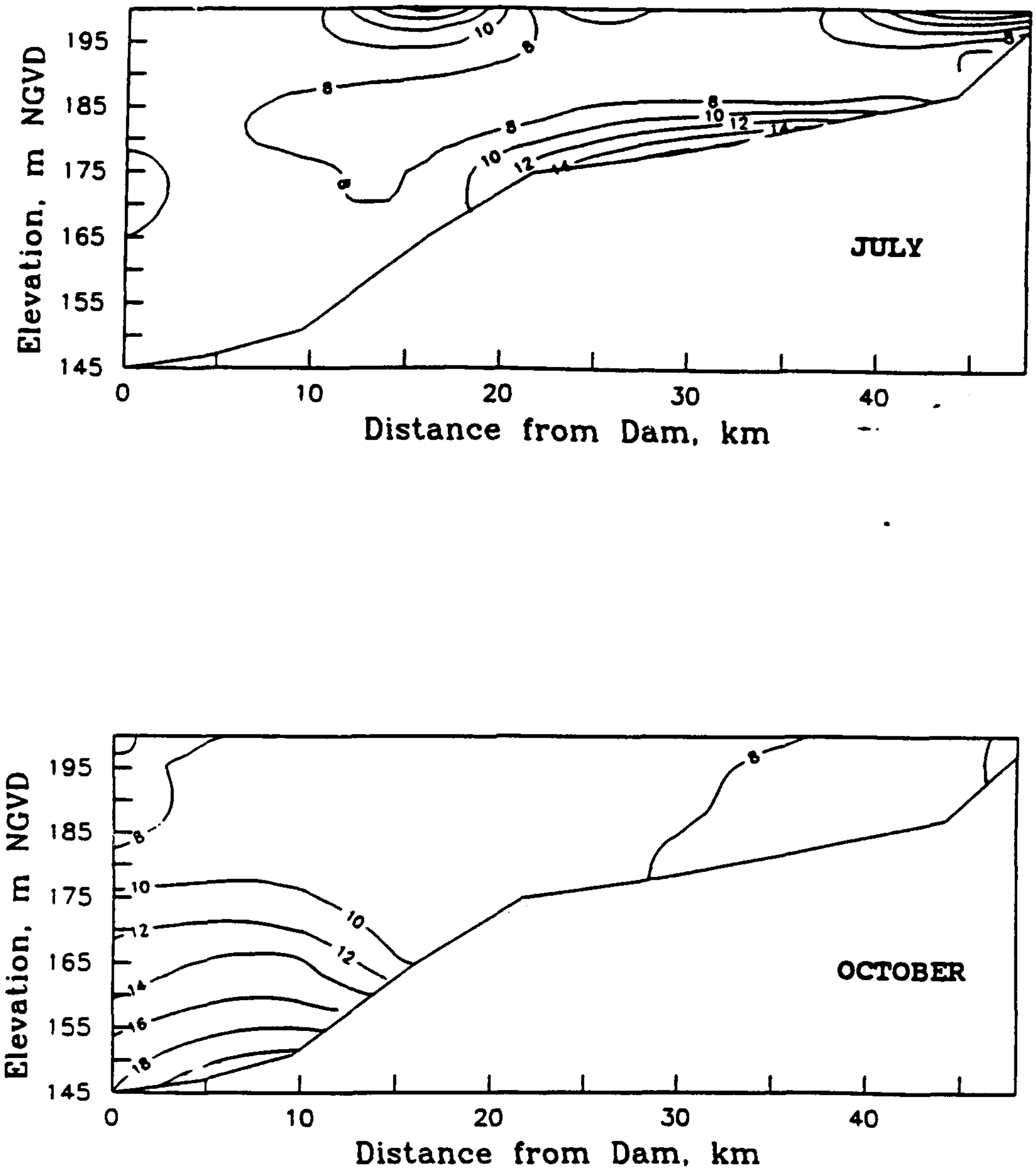


Figure 33. Patterns of spatial distribution of total alkalinity (mg/l) from Hartwell Dam to upper Tugaloo River, July and October 1991

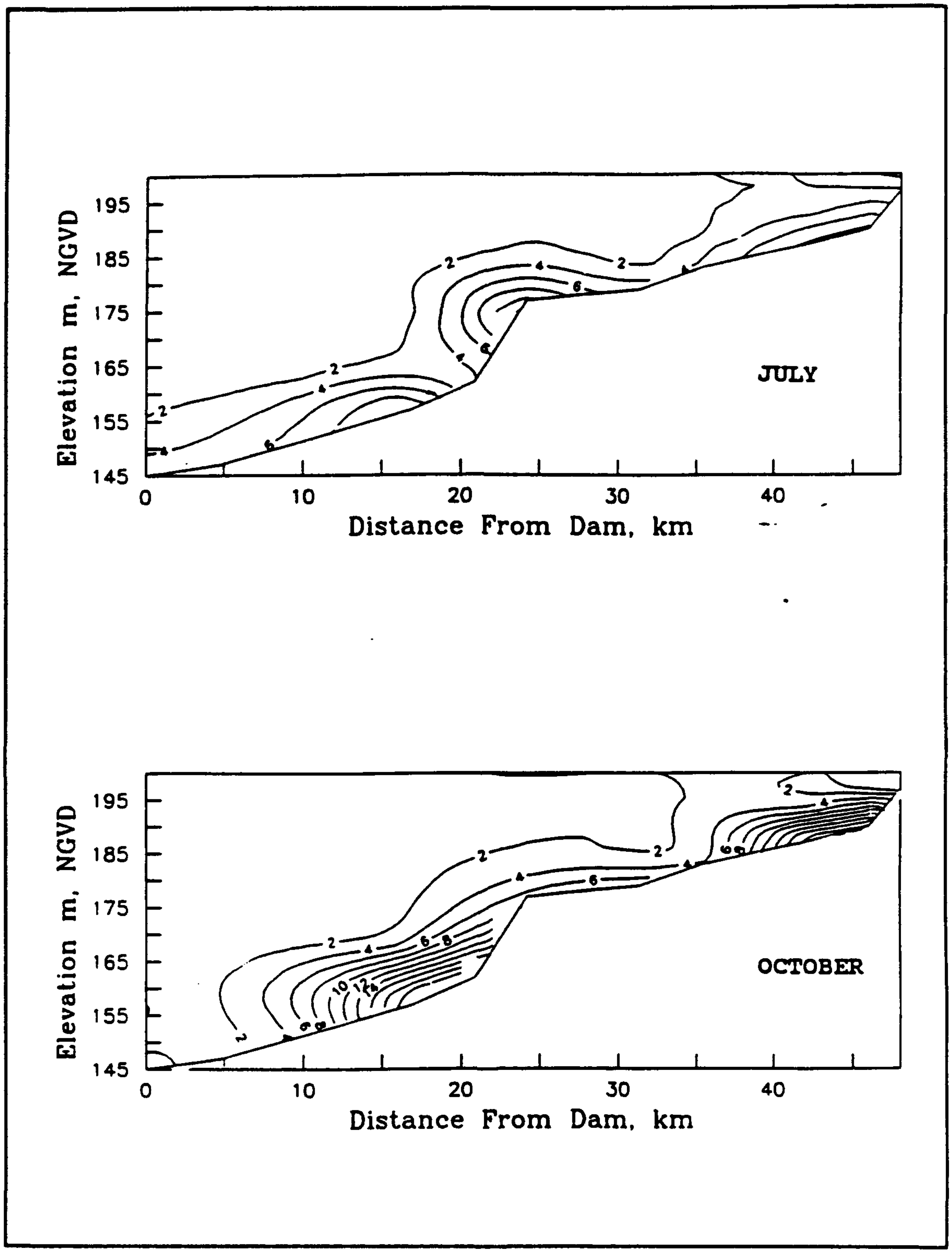


Figure 34. Patterns of spatial distribution of turbidity (ntu) from Hartwell Dam to upper Seneca River, July and October 1991

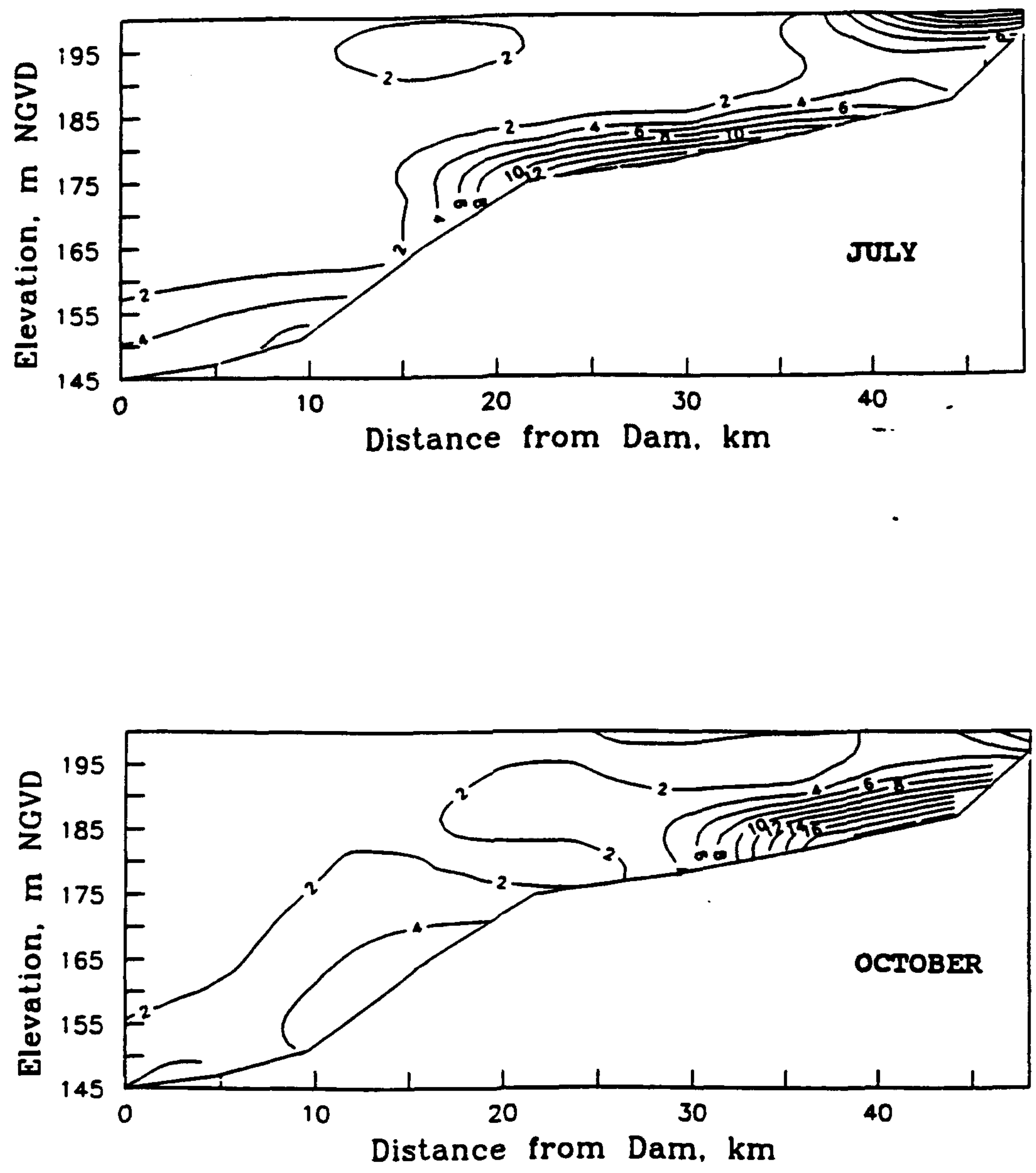


Figure 35. Patterns of spatial distribution of turbidity (ntu) from Hartwell Dam to upper Tugaloo River, July and Octob 1991

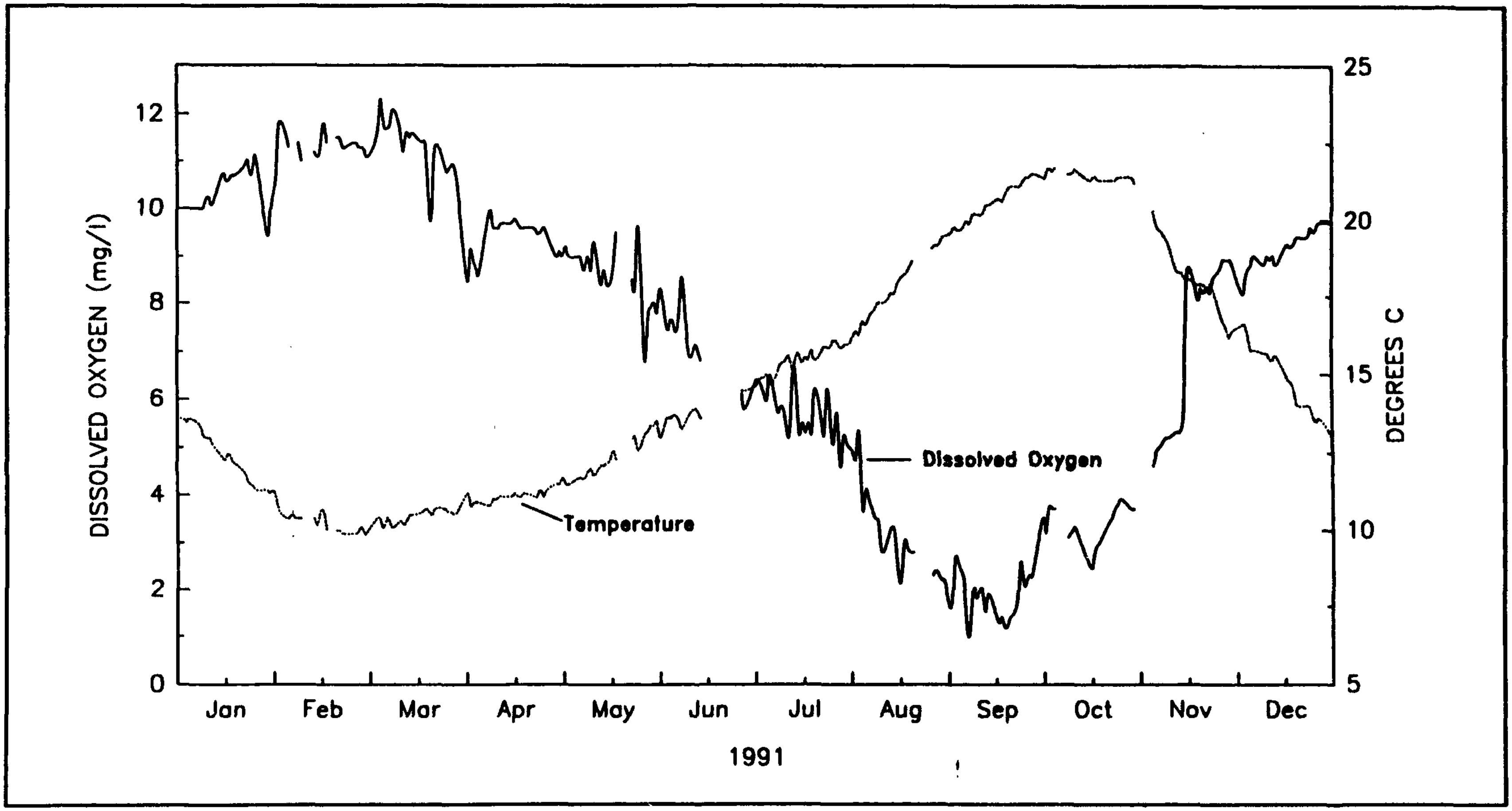


Figure 36. Temporal changes in daily mean temperature and dissolved oxygen concentrations (mg/l) for Hartwell Lake release water during 1991

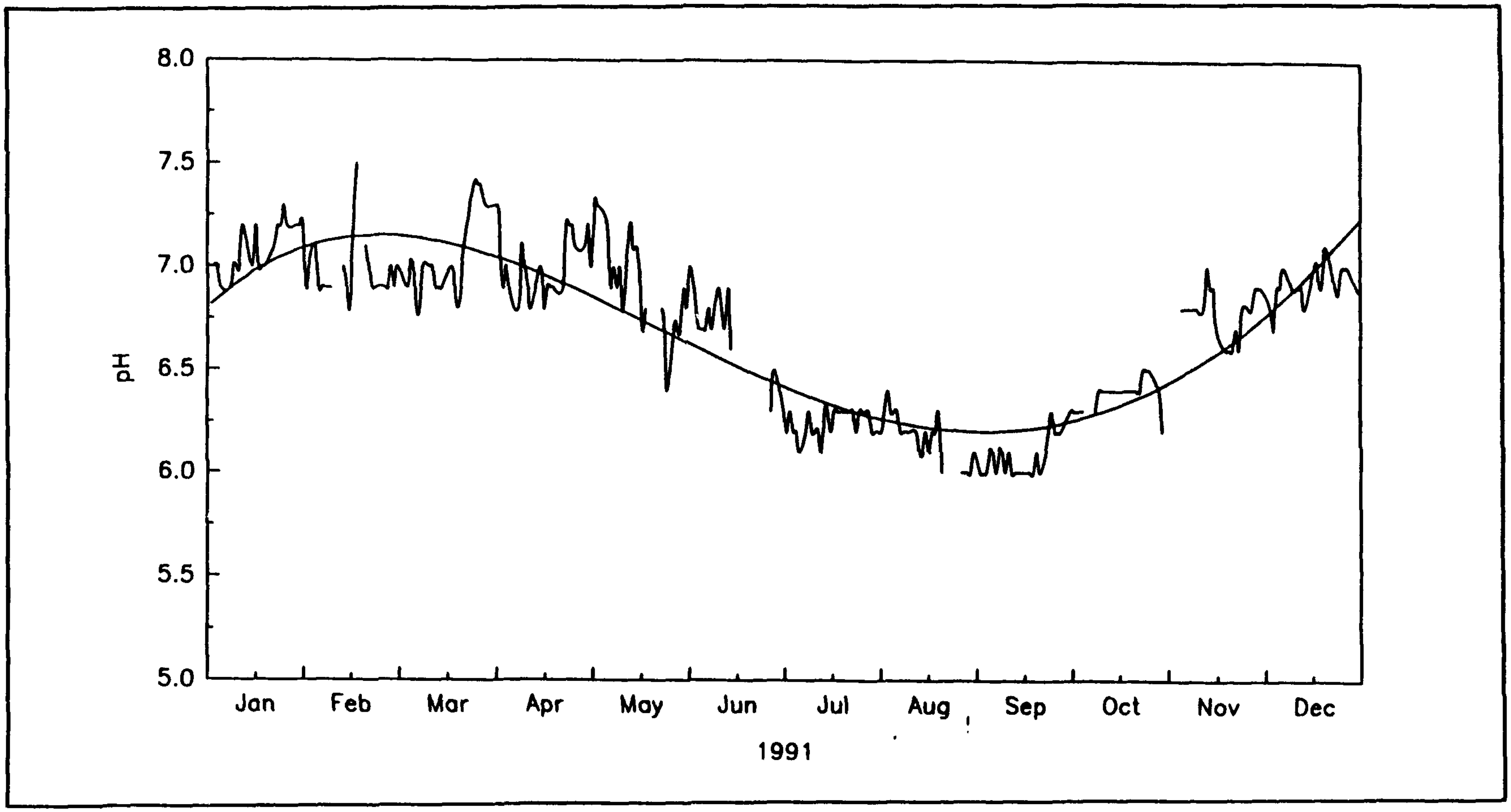


Figure 37. Temporal changes in daily mean pH (pH units) for Hartwell Lake release water during 1991

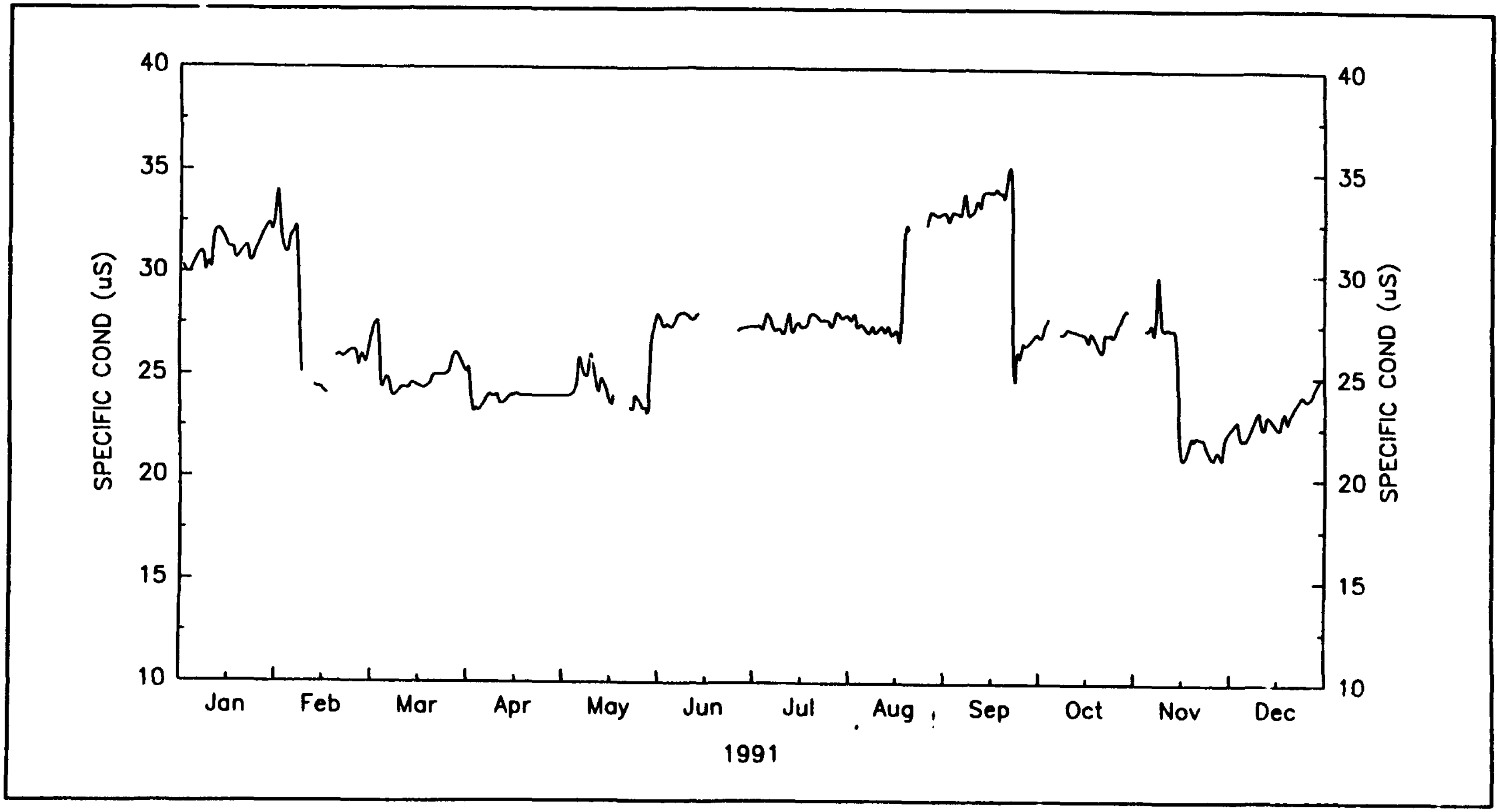


Figure 38. Temporal changes in daily mean specific conductance (µS) for the Hartwell Lake release water during 1991

Table 1
List of Variables

In Situ	**Nutrients**
Temperature	Total organic carbon
Dissolved oxygen	Dissolved organic carbon
pH	Total phosphorus
Specific conductance	Total soluble phosphorus
	Soluble reactive phosphorus
Physicochemical	Total nitrogen
Turbidity	Total soluble nitrogen
Total alkalinity	Ammonium-nitrogen
	Nitrate-nitrite nitrogen

Table 2
Summary of Hartwell Lake Epilimnetic In Situ and Water Chemistry Data for 15 July 1991

Variable[1]	Mean[2]	Minimum	Maximum	n[3]
Dissolved Oxygen	8.4	4.1	9.8	91
Temperature, °C	28.0	19.5	32.0	91
Specific Conductance, μS	28.5	19.0	40.0	91
pH, pH units	7.2	6.2	8.0	91
Turbidity, NTU's	3.3	1.3	30.0	32
Suspended Solids	7.3	0.8	31.6	9
Total Alkalinity	9.1	6.3	16.9	32
Total Organic Carbon	1.2	0.4	2.2	32
Dissolved Organic Carbon	1.1	0.4	2.2	32
Total Phosphorus	0.015	0.007	0.081	32
Total Soluble Phosphorus	0.007	0.005	0.050	32
Soluble Reactive Phosphorus	0.005	0.005	0.009	32
Total Nitrogen	0.39	0.22	0.83	32
Dissolved Nitrogen	0.31	0.18	0.90	32
Ammonia Nitrogen	0.021	0.20	0.050	32
Nitrate Nitrite Nitrogen	0.052	0.40	0.220	32
Total Manganese	0.09	0.05	0.22	32
Dissolved Manganese	0.06	0.05	0.15	32
Total Iron	0.26	0.05	3.28	32
Dissolved Iron	0.10	0.05	1.49	32

1 Units are mg/l except for noted variables.
2 Means are calculated using detection limit values.
3 n = Number of observations on which calculations are based.

Table 3
Summary of Hartwell Lake Hypolimnetic In Situ and Water Chemistry Data for 15 July 1991

Variable[1]	Mean[2]	Minimum	Maximum	n[3]
Dissolved Oxygen	2.1	0.1	8.7	169
Temperature, °C	17.8	11.2	25.7	169
Specific Conductance, µS	35.7	19.0	80.0	169
pH, pH units	6.5	6.0	7.5	169
Turbidity, NTU's	4.9	0.7	27.0	39
Suspended Solids	7.4	2.0	16.8	5
Total Alkalinity	11.3	6.3	23.8	40
Total Organic Carbon	0.8	0.2	1.7	38
Dissolved Organic Carbon	0.7	0.1	1.5	37
Total Phosphorus	0.012	0.005	0.050	40
Total Soluble Phosphorus	0.006	0.005	0.010	40
Soluble Reactive Phosphorus	0.005	0.005	0.005	40
Total Nitrogen	0.51	0.21	1.02	40
Dissolved Nitrogen	0.46	0.29	1.00	40
Ammonia Nitrogen	0.077	0.020	0.410	40
Nitrate Nitrite Nitrogen	0.135	0.040	0.460	40
Total Manganese	0.38	0.05	1.80	40
Dissolved Manganese	0.37	0.05	1.80	40
Total Iron	0.69	0.05	3.60	40
Dissolved Iron	0.42	0.05	3.60	40

1 Units are mg/l except for noted variables.
2 Means are calculated using detection limit values.
3 n = Number of observations on which calculations are based.

Table 4
Summary of Hartwell Lake Epilimnetic In Situ and Water Chemistry Data for 23-24 October 1991

Variable[1]	Mean[2]	Minimum	Maximum	n[3]
Dissolved Oxygen	8.1	5.9	9.7	60
Temperature, °C	20.7	17.7	22.3	60
Specific Conductance, µS	31.0	21.0	40.0	60
pH, pH units	6.4	6.0	7.4	60
Turbidity, NTU's	2.4	0.8	6.0	16
Total Alkalinity	9.1	6.3	11.7	16
Total Organic Carbon	1.5	1.0	1.8	16
Dissolved Organic Carbon	1.2	1.0	1.5	16
Total Phosphorus	0.030	0.009	0.171	16
Total Soluble Phosphorus	0.006	0.005	0.018	16
Soluble Reactive Phosphorus	0.005	0.005	0.007	16
Total Nitrogen	0.22	0.04	0.76	16
Dissolved Nitrogen	0.11	0.02	0.21	16
Ammonia Nitrogen	0.04	0.02	0.18	16
Nitrate Nitrite Nitrogen	0.04	0.04	0.05	16
Total Manganese	0.05	0.05	0.08	16
Dissolved Manganese	0.05	0.05	0.05	16
Total Iron	0.25	0.14	0.70	16
Dissolved Iron	0.05	0.05	0.05	16

1 Units are mg/l except for noted variables.
2 Means are calculated using detection limit values.
3 n = Number of observations on which calculations are based.

Table 5
Summary of Hartwell Lake Hypolimnetic In Situ and Water Chemistry Data for 23-24 October 1991

Variable[1]	Mean[2]	Minimum	Maximum	n[3]
Dissolved Oxygen	5.7	0.1	8.4	126
Temperature, °C	19.9	13.7	21.3	126
Specific Conductance, µS	37.3	21.0	85.0	126
pH, pH units	6.2	5.8	6.7	126
Turbidity, NTU's	5.3	1.0	22.0	27
Total Alkalinity	11.8	6.5	23.2	28
Total Organic Carbon	1.8	1.2	3.5	28
Dissolved Organic Carbon	1.4	0.8	2.8	28
Total Phosphorus	0.032	0.008	0.171	27
Total Soluble Phosphorus	0.010	0.005	0.035	28
Soluble Reactive Phosphorus	0.008	0.005	0.034	28
Total Nitrogen	0.40	0.06	1.40	28
Dissolved Nitrogen	0.29	0.02	0.97	28
Ammonia Nitrogen	0.18	0.02	0.92	28
Nitrate Nitrite Nitrogen	0.05	0.04	0.17	28
Total Manganese	0.39	0.05	1.50	28
Dissolved Manganese	0.37	0.05	1.50	28
Total Iron	2.25	0.15	10.35	28
Dissolved Iron	1.71	0.05	9.20	28

[1] Units are mg/l except for noted variables.
[2] Means are calculated using detection limit values.
[3] n = Number of observations on which calculations are based.

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13. ABSTRACT *(Maximum 200 words)*

Hartwell Lake, located between Georgia and South Carolina along the Savannah River basin, was the site of an extensive water quality study during 1991. Temporal and longitudinal trends were identified through monthly in situ monitoring and bi-annual chemical analyses.

The onset of thermal stratification began on Hartwell Lake during late March. By May, extensive stratification was present from headwaters to the forebay. Anoxic conditions were first observed in the middle reaches of the Seneca and Tugaloo River embayments during the July sampling. The greatest concentrations of chemical constituents within the tributary embayments were recorded during the mid- to late summer period. Progression of the anoxic zone from the mid-embayments towards Hartwell Dam was observed during the July through October period. Stratification and accompanying anoxia in the upstream regions were diminished by early October due to seasonal cooling and mixing processes. In the deepwater near-dam areas, anoxic conditions persisted until November.

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An intensive physicochemical sampling effort during July revealed the presence of increased concentrations of specific nutrients and organic carbons associated with anoxic conditions in the bottom waters of each tributary embayment. Chemical concentrations within the mid-reaches of the Seneca River embayment were consistently greater than those observed within the Tugaloo River arm. July was significant in that the sampling study coincided with the greatest monthly rainfall of the 1991 year.

A second intensive sampling trip conducted in late October revealed that, due to autumnal mixing, anoxia within the tributary embayments no longer existed. Consequently, chemical constituents found in high concentrations within the Seneca and Tugaloo embayments during July were greatly diminished during October. Anoxic conditions were observed in the bottomwaters of the deep near-dam stations. Maximum concentrations of chemical variables were recorded in these areas during October.

Continuous data for temperature, dissolved oxygen, pH and conductivity were collected using a Schneider RM-25 monitor in the tailrace below Hartwell Dam. These data reflected seasonal variability and were indicative of water quality conditions within the Hartwell Lake forebay.

Hartwell Dam outflows during July and August 1991 were nearly double those for the same months during the previous year. This increased outflow was in response to greater than average rainfall. Inflows during August 1991 were three times greater than during August 1990.

In summation, water quality conditions at Hartwell Lake were influenced by multiple factors, including hydrodynamics, loading, climatological conditions, seasonal variability, algal productivity, anoxic development and duration, bottom water-sediment interactions, and additional internal and external limnological processes. Studies conducted on two downstream Savannah River system lakes, Richard B. Russell and J. Strom Thurmond, recorded similar patterns of temporal and longitudinal gradients with regard to in situ and physicochemical parameters. Longitudinal, vertical and temporal variability were readily observed in temperature, dissolved oxygen, pH and specific conductance in situ data during 1991. Nutrient, organic carbon, and alkalinity concentrations were greatly influenced by the presence of anoxia in Hartwell Lake bottom waters.